GEOLOGY OF THE NORTHERN MINERAL RANGE, MILLARD AND BEAVER COUNTIES, UTAH

by

Homer C Liese

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by

Homer C Liese

has been approved by

[redacted] Supervisory Committee

Reader, Supervisory Committee

Reader, Supervisory [redacted]

Head, Major Department

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INTRODUCTION

Purpose and Scope of Report

The primary purpose of this investigation was the mapping of the northern part of the Mineral Range on a scale of approximately 1:20,000, and the preparation of a report on the structure, stratigraphy, igneous and metamorphic rocks which are present. An attempt has also been made to reconstruct the geologic history of the area.

The geology of the Northern Mineral Range, as it will be referred to in this report, is complex. This is chiefly because: (1) almost all of the sedimentary rocks in the area probably belong to the same stratigraphic system and were found to be, in general, unfossiliferous; (2) the area lies within a belt of thrusting; (3) the Northern Mineral Range has been the site of igneous activity on a relatively large scale; and (4) normal faults and local areas of metamorphism are abundant. As a result, conclusive geologic evidence as to the age and complete nature of some tectonic features has not been discovered by the writer. This has necessitated, in certain instances, the formulation of hypotheses rather than definite conclusions.

The rocks are described with regard to: (1) general physiographic expression and position; (2) petrologic and petrographic characteristics; (3) age and correlation; (4) origin; (5) relation to other rocks; and (6) alteration.

This investigation does not represent the final word on the geology of the Northern Mineral Range. Much research remains to be done, and as will be shown later, several interesting field and laboratory problems are available for future academic study.

Location and Accessibility

The Mineral Range is located in the eastern part of Beaver County, Utah, and extends generally northward into the southeastern part of Millard County. However, the area mapped and described in this report, the Northern Mineral Range, has a north-northwest trend. This region includes most of T. 26 S. and T. 25 S., the western part of R. 8 W., and the eastern part of R. 9 W., Salt Lake Base and Meridian (See geologic map, Fig. 1, and index map, Fig. 2). The Northern Mineral Range comprises an area of approximately 25 square miles, the northernmost part of which is about 155 air miles south-southwest of Salt Lake City.

In regard to physiographic setting, the Mineral Range is located at the eastern margin of the Basin and Range Province. About 15 miles to the east are the Tushar Mountains, which are located in the transitional zone between the High Plateaus of Utah and the above mentioned Province. The San Francisco Mountains are about 20 miles to the west. Semi-arid plains, which immediately surround the Mineral Range, are in part overlain by predominantly basic lava flows and several volcanoes

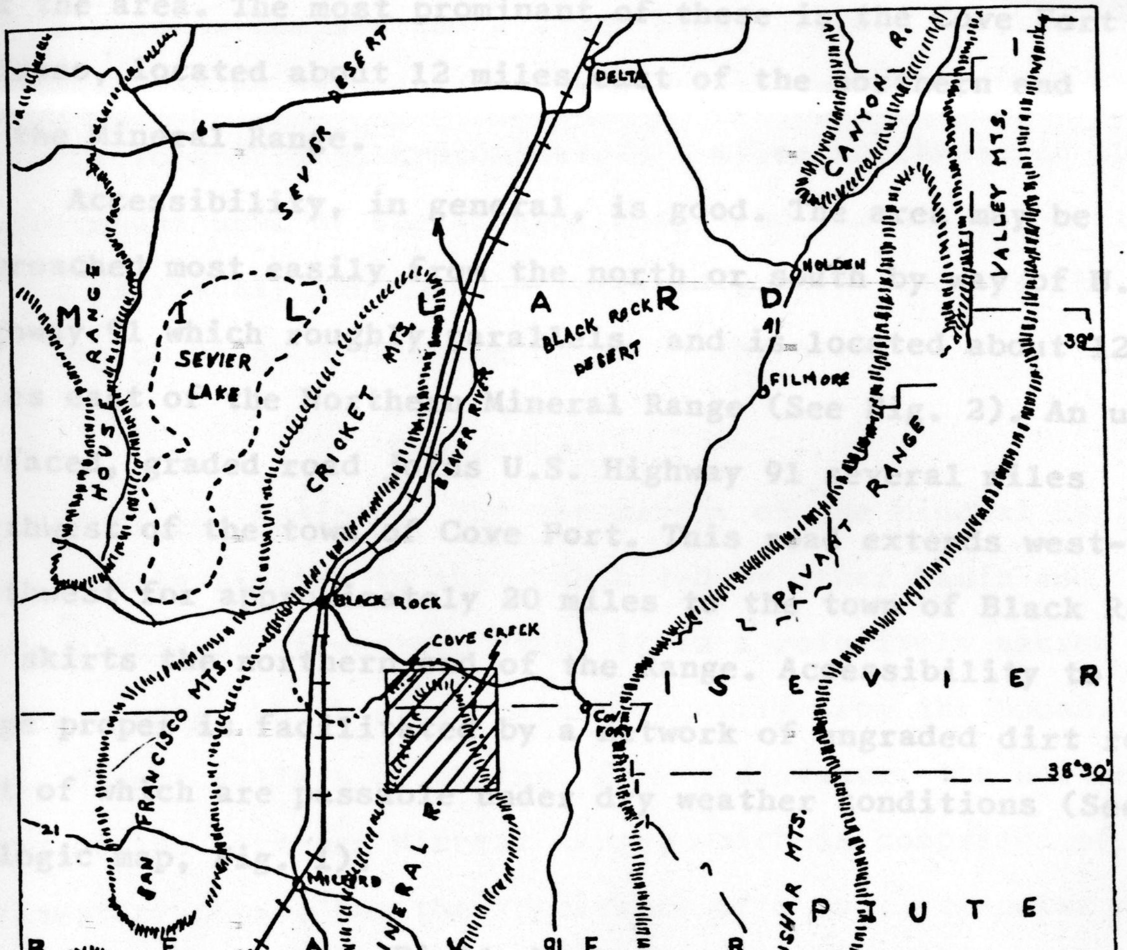


Figure 2. INDEX MAP

Location and physiographic setting of the Northern Mineral Range, Utah, which is shown as ruled area.

dot the area. The most prominant of these is the Cove Fort volcano, located about 12 miles east of the northern end of the Mineral Range.

Accessibility, in general, is good. The area may be approached most easily from the north or south by way of U.S. Highway 91 which roughly parallels, and is located about 12 miles east of the Northern Mineral Range (See Fig. 2). An unsurfaced, graded road joins U.S. Highway 91 several miles northwest of the town of Cove Fort. This road extends west-northwest for approximately 20 miles to the town of Black Rock, and skirts the northern end of the Range. Accessibility to the range proper is facilitated by a network of ungraded dirt roads, most of which are passable under dry weather conditions (See geologic map, Fig. 1).

Field Work

Field work was mostly done during the summer of 1956, but numerous weekend trips to the area were necessary during the following school year.

Field mapping was accomplished on aerial photographs of a scale of 1:20,000, obtained from the Soil Conservation Service at Washington D.C. A base map was compiled at approximately the same scale with the use of a controlled aerial mosaic supplied by the Standard Oil Company of California at Salt Lake City. Section corners were discovered in the field, and their positions noted on the photographs. Where corners could not be located, their positions were arbitrarily plotted by interpolation from known points. Stratigraphic sections were measured with a brunton compass and a tape. Stratigraphic thicknesses were computed by trigonometric and graphic means.

Antelope Spring, approximately 3 miles northwest of the northernmost spur of the Mineral Range and immediately south of the previously mentioned unsurfaced graded road, is the only source of good drinking water in the area.

Geography

Topography and drainage. The topography of the Mineral Range is generally similar to that exhibited by other Basin and Range highlands of western Utah. It is a relatively narrow mountain range which rises rather abruptly from the broad, flat, desert valleys or plains. From a distance, the northern third of the Northern Mineral Range, which is comprised of sedimentary rocks, has the appearance of a low, irregular dome, but on closer approach it is observed to be composed of numerous ridges and intervening canyons and valleys which trend essentially perpendicular to the principal north-northwest axis (See Plate 1). The remainder of the area mapped is made up of igneous rocks, and exhibits surface features which are in general more rugged and irregular than those of the northern third. The crest of the Northern Mineral Range has an elevation of about 5,500 feet near the north end to 7,700 feet in the southern part. In general, the relief ranges from less than 1,500 feet in the northern third to more than 2,000 feet near the southern end of the area mapped. In the Central Mineral Range, the rugged surface rises to a height of 11,000 feet, and the highest peaks have a relief which exceeds 5,000

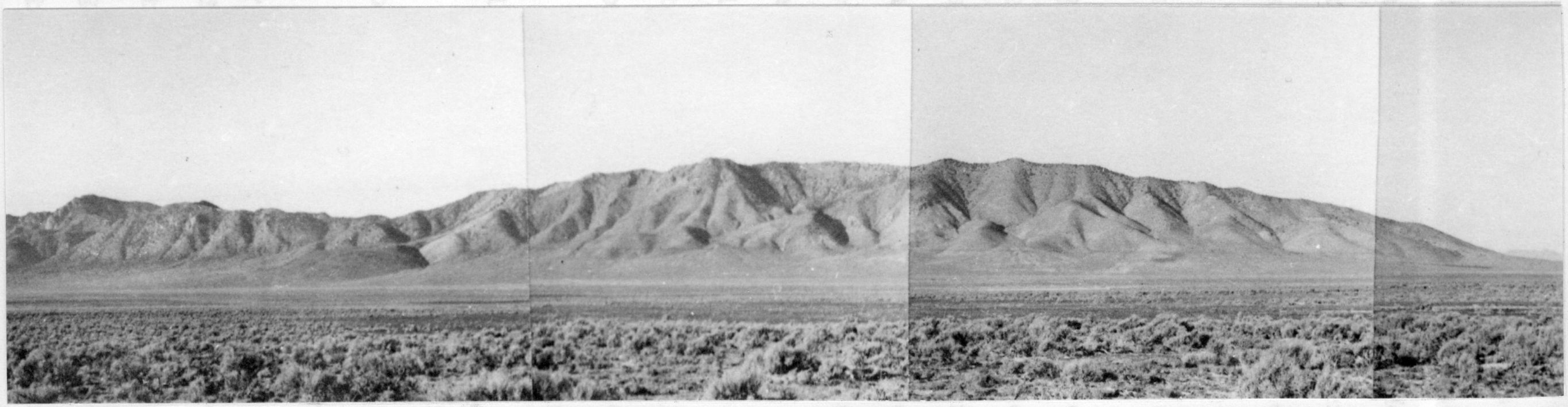


Plate 1.—General topography of the northern part of the Northern Mineral Range. View is westward.

feet.

There are no perennial streams in the area, and most of the year the valleys and washes leading across the desert plains from the Range are entirely dry. However, upon occasion, a cloudburst occurs at the headwaters of one of the canyons or valleys, and the subsequent muddy torrent floods the lowlands. All of the area drains into Cove Creek, which ultimately empties into the Beaver River (See Fig. 2).

Climate and vegetation. The climate of the area may be classified as temperate and dry with mild summers and cold winters. Annual differences of temperature, for January and July, are 45° to 55°. Diurnal temperature ranges are relatively large, 25° to 35° in July and 15° to 25° in January. Summer day temperatures average between 85° and 95°, but owing to the low humidity and local winds the days are not excessively warm. Summer nights are nearly always delightfully cool.

Precipitation does not usually exceed 12 inches in the valley plains and the Northern Mineral Range. Most of the moisture which falls between November and March is in the form of snow, but does not remain on the ground as such for any great length of time. June, July, and August are the driest months and are lacking in precipitation except for a few thunderstorms.

The surrounding desert plains are covered with sagebrush for the most part, characteristic of the scanty vegetation of arid regions. Several varieties of cactus occur in the area, but these are nowhere abundant. Juniper and piñon trees, commonly referred to as cedars, are numerous only in the higher parts of the area mapped. These trees are not large, having diameters generally less than one foot.

Land utilization and population. Land utilization is restricted to grazing for horses and cattle and the flocks of sheep which are annually driven through the region.

There is no human population except for the occasional sheepherder, rancher, or prospector.

Previous Investigations

Previous geologic investigations of the Northern Mineral Range have been essentially confined to work done by the U.S. Geological Survey and the Utah State Geological Survey.

B.S. Butler (1913, 1920) was probably the first to write about the general geology of the Northern Mineral Range. Crawford and Buranek (1942, 1945) have described the mineral deposits of the area mapped, especially the tremolitized limestones located in Sec. 25, T. 25 S., R. 9 W., and have also discussed the general geology. The above mentioned authors and their publications are listed in the bibliography.

The Central Mineral Range has undergone more numerous and more detailed investigations than the area described in this report. At the present time, F.N. Earll (University of Utah) is completing a geologic study of the Central Mineral Range.

STRATIGRAPHY

General Statement

Almost all of the sedimentary rocks exposed in the Northern Mineral Range are probably Cambrian in age. No known Precambrian or younger Paleozoic rocks are exposed in the area. Outcrops of Cretaceous(?) conglomerate are located in the northernmost part of the Range, in the vicinity of Lead Canyon. Quaternary(?) limestone of lacustrine origin crops out, in isolated patches, on the alluviated valley plain west of the Range. Deposits of known Quaternary age consist of shore deposits, alluvium, talus debris, and consolidated gravels. All of the Cambrian and Cretaceous(?) sedimentary rocks occur in the northern third of the area mapped, north of the well defined, major igneous-sedimentary contact (See Fig. 1). In order to facilitate readability, when considered as one unit, this section will hereafter be referred to as the sedimentary division.

The predominant constituents of the sedimentary division are limestone and quartzite or quartzose sandstone. Conglomerate, shale, and dolomite are subordinate.

The paucity of fossils and local metamorphic effects have made age determinations and stratigraphic correlation difficult, and in part problematical. In fact, the only identifiable fossil fragments were collected from a shale exposure in a single locality in Sec. 23, T. 25 S., R. 10 W. (See section on Pioche shale).

Precambrian(?) Rocks

The only rocks present in the Northern Mineral Range which may be of Precambrian age, constitute a dark, basic, ferromagnesium-rich zone located along the western margin of the granitic mass (See Fig.1). The rocks are predominantly of granular texture and dioritic composition. According to Earll (personal communication), they grade into gneissic rocks in the Central Mineral Range and are thought to be Precambrian in age.

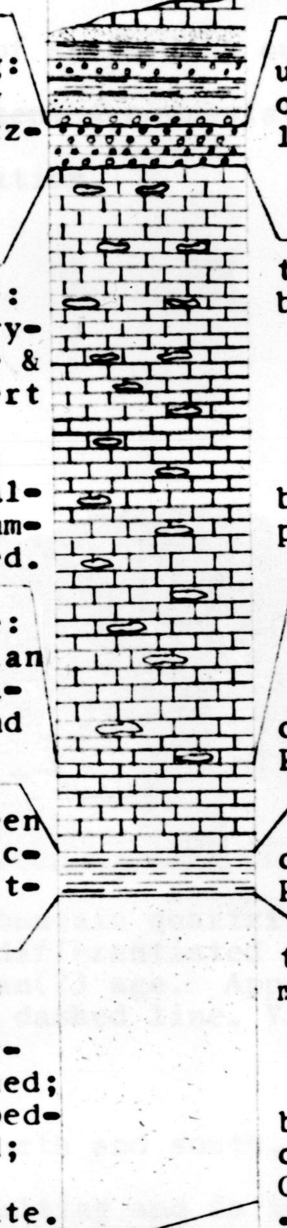
Due to the fact that the writer has not been able to discover sufficient evidence in the Northern Mineral Range to support a Precambrian age assignment, and since Earll has not yet completed his investigation of the area in question, the basic zone of the Northern Mineral Range has been depicted on the geologic map without any precise age specification. A detailed description of the basic zone of the Northern Mineral Range, and its relationship to the granite with which it is in contact, are presented in the section on metamorphic zones.

Cambrian System

Rocks of known Cambrian age include three distinct lithologic units. A lower quartzite unit; a middle shale unit; and an upper unit composed of carbonate rocks. The shale and carbonate units have locally been subjected to hydrothermal alter-

COMPOSITE STRATIGRAPHIC SECTION OF NORTHERN MINERAL RANGE

AGE		NAME and LITHOLOGY	SECTION	THICKNESS and STRAT. REL.
QUATERNARY		lake limestone (Tertiary(?)) shore deposits talus debris consolidated gravels alluvium		0' to 3500'
(?) CRETACEOUS	Lower (?)	Indianola(?) cong: fragments chiefly limestone & quartzite; granules to cobbles; matrix limestone.		unconformably on Cambrian limestone 110'
CAMBRIAN(?)	Middle or Upper	Undiff. limestone: banded; finely crystalline; massive & thick bedded; chert lenses common to light gray bands; chert nodules, calcite veinlets common; partly altered.		top terminated by thrust 1285' base not exposed
CAMBRIAN	Middle (?)	Undiff. limestone: similar to Cambrian (?) ls., but metamorphosed more and no chert lenses.		190' conformably on Pioche shale
CAMBRIAN	Middle	Pioche shale: green to olive drab; micaceous; partly altered.		25' to 100' conformably on P.M. quartzite
CAMBRIAN	Lower to Middle	Prospect Mountain quartzite: white, pink, gray, & purple; medium grained; massive & thick bedded; cross bedded; lenses of quartz pebble conglomerate.		top partly removed by eros. 775'(max.) base in thrust contact with Cambrian(?) ls. or not exposed



ation and contact metamorphism, especially in the vicinity of fault zones and proximate to the igneous mass. The reader is referred to the section on metamorphic zones for discussion in detail.

In the central part of the sedimentary division, the Cambrian Prospect Mountain quartzite forms the crest of the Range (See Plate 2). Here, the formation is less than 200 feet thick, and is underlain by a thick (1200 feet), younger Cambrian(?) limestone unit. Several patches of shale crop out on top of the quartzite, and probably represent a nonresistant member within the Prospect Mountain formation.

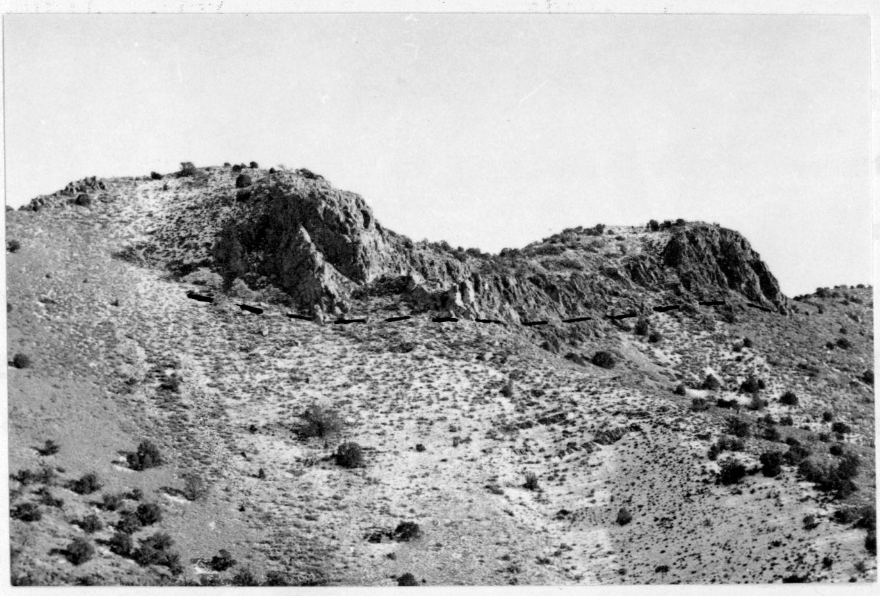


Plate 2.—Prospect Mountain quartzite overlying sequence of undifferentiated limestones of younger Cambrian(?) age. Approximate contact is shown by dashed line. View is southeastward.

However, to the immediate north and south, the Range has undergone normal east-west downfaulting and is represented by the entire Cambrian quartzite-shale-carbonate sequence (See Fig. 1, cross section A-A').

The writer believes that the Cambrian sequence mentioned above comprises an overthrust plate, overlying limestones of younger Cambrian(?) age. (Refer to section on structure for discussion of the Northern Mineral Range thrust).

Prospect Mountain Quartzite

Lithology. The Prospect Mountain quartzite exposed in the Northern Mineral Range is in general a medium grained rock, which ranges in color from light gray to pink and to darker purple and medium gray. The quartzite is massive and thick bedded where it is exposed as bedrock, and everywhere the beds are heavily fractured. There are many quartzite talus deposits comprised chiefly of angular fragments ranging from cobble to boulder size. Cross bedding is a common sedimentary structure of the quartzite, and local lenses of quartz pebble conglomerate are found in places (See Plate 3).

Age and correlation. No fossils were found in the Prospect Mountain quartzite of the Northern Mineral Range. However, the fact that the quartzite lies conformably below a shale formation which contains Middle Cambrian fossil fragments is sufficient evidence that the quartzite is probably of late Lower to Middle Cambrian age.

Correlation, based on lithology and stratigraphic sequence, is possible with the San Francisco and Cricket Mountains which are located about 20 miles west and northwest of the Northern Mineral Range (See Fig. 2). E.H. East (1957) reports a Cambrian quartzite-shale-carbonate sequence in the Cricket Mountains which is similar to that exposed in the Northern Mineral Range. East also provides evidence supporting the existence of an overthrust plate comprised of Precambrian and Cambrian quartzites in the northern part of the San Francisco Mountains.

Plate 3.-Hand specimens of Prospect Mountain quartzite found in the Northern Mineral Range, showing variation in color and texture. From left to right: white to pink; medium gray; white to light gray with darker gray and purple bands; and quartz pebble conglomeritic lens in purple specimen. Conglomeritic lenses were also found in white and medium gray members of the formation.

The writer acknowledges the fact that the Prospect Mountain quartzite is in part lithologically similar to, and may be mistaken for, younger quartzites which are exposed in other parts of Utah and Nevada. Therefore, in the absence of fossils, age and correlation must be based on both lithology and stratigraphic sequence if fairly accurate results are to be obtained.

Measured section. The following section of Prospect Mountain quartzite was measured in the northeast quarter, Sec. 23, T. 25 S., R. 10 W.

It was necessary to break the section between units 5 and 6 owing to the presence of a fault zone represented by a canyon. As a result, the total measured 1006 feet of Prospect Mountain quartzite represents the absolute maximum thickness exposed in the Northern Mineral Range. Units 1 through 5 are continuous and represent the probable maximum thickness of 778 feet.

		Feet
Cambrian-Pioche shale:		
Cambrian-Prospect Mountain quartzite:		
Unit 7.	Quartzite; light gray to pink, weathering light brown, medium grained "sugary" texture; forms a ledge. Much green shale float.	90
Unit 6.	Covered quartzite talus slope; fragments light gray to pink, angular, and medium grained. Boulders and cobbles predominant fragment size.	138
	Broke section--fault	
Unit 5.	Covered quartzite talus slope; fragments light gray almost white, weathering light brown, medium to coarse grained; fragment size and shape as in #6.	173
Unit 4.	Covered quartzite talus slope; lithology as in #6.	190
Unit 3.	Quartzite; pink to light gray, weathering yellowish to medium gray, medium grained, massive, resistant; jointed; surface cross bedded. Quartz pebble conglomeritic lens 6 inches wide and about 25 feet long.	50

Measured section (contd.)

Unit 2.	Quartzite; medium gray, weathering medium to dark gray; texture, type of exposure as in #3. Quartz pebble conglomeritic lens as in #3 but of smaller size.	65
Unit 1.	Covered quartzite talus slope; fragments pink and all shades of gray, weathering pink, gray, and red-brown; texture as in #7; roundness as in #6; fragment size predominantly cobbles.	300

Total measured absolute maximum thickness of exposed Prospect Mountain quartzite (Units 1--7)............. 1006

Total measured probable maximum thickness of exposed Prospect Mountain quartzite (Units 1--5)............. 778

Pioche Shale

Lithology. The Pioche shale in the Northern Mineral Range is generally a nonresistant formation, altered in part, which crops out chiefly as small isolated patches in place and as areas of float. However, in the vicinity of the major igneous-sedimentary contact and adjacent to the altered Cambrian limestone, the Pioche shale has been metamorphosed to argillite which is rather resistant to erosion and consequently has retained much of its original outcrop character (See Plate 4).

The relatively unmetamorphosed shale, in the areas where it is exposed, is a micaceous rock, the color of which ranges from olive drab to green. Numerous worm(?) tracks and trails characterize the shale in almost every locality. According to Mrs. Balk* (personal communication), such trails were called

*Mrs. C.L. Balk, presently associated with the New Mexico Institute of Mining and Technology, is considered to be one of the leading authorities on Middle Cambrian paleontology. A published example of one of her recent studies is listed in the bibliography.

Cruziana by Walcott, but the exact animal or algae which may have made them is not known.

Exposure thicknesses of the Pioche shale range from less than 25 feet to more than 100 feet, the thickest section being located in the metamorphic zone near the igneous-sedimentary boundary. In nearly every exposure the shales dip steeply and are not traceable for any great distance. Undoubtedly, this is primarily the result of faulting, which is such a predominant factor in the development of the Range.

Age and correlation. The only identifiable fossil fragments found in the Pioche shale were identified by Mrs. Balk as heads, tails, and free cheeks of Glossopleura producta. This species was originally described from the Ophir shale in the Oquirrh Mountains, Utah, and represents the Glossopleura zone of the Middle Cambrian. Mrs. Balk also states that the rest of the material sent to her for identification, and collected by the writer from 5 different localities including the shales on the crest of the Range, are characteristic of the transgressive shales of the Middle Cambrian although not containing significant faunal remains.

Of special interest are those samples which exhibit tracks and trails (See Plate 5), of which Mrs. Balk states the following:

> "This type of rock and surface is characteristic of the early Middle Cambrian transgressive shales through Utah, Montana, and Wyoming, and they range widely from late Lower Cambrian to as high as middle Middle Cambrian in age, so the specimens cannot be used for determining the age. The shales were probably neritic, not shallow and exposed, and may have been deposited in depths exceeding 100 feet."

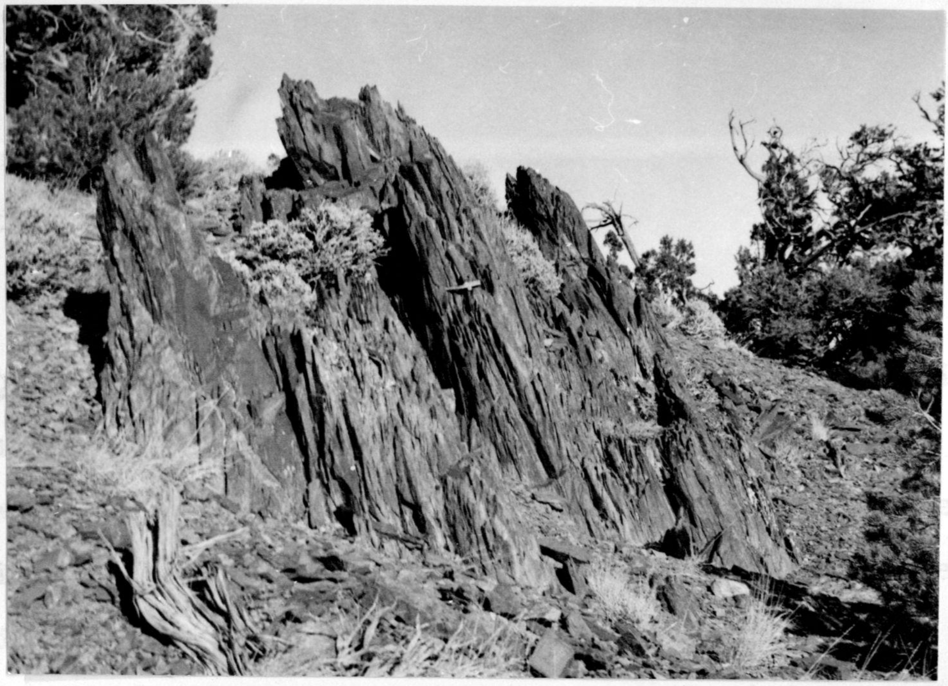


Plate 4.—Resistant outcrop of partly metamorphosed Pioche shale (argillite) in contact zone near granodiorite. View is eastward. Note inverted geology pick near center of photograph.

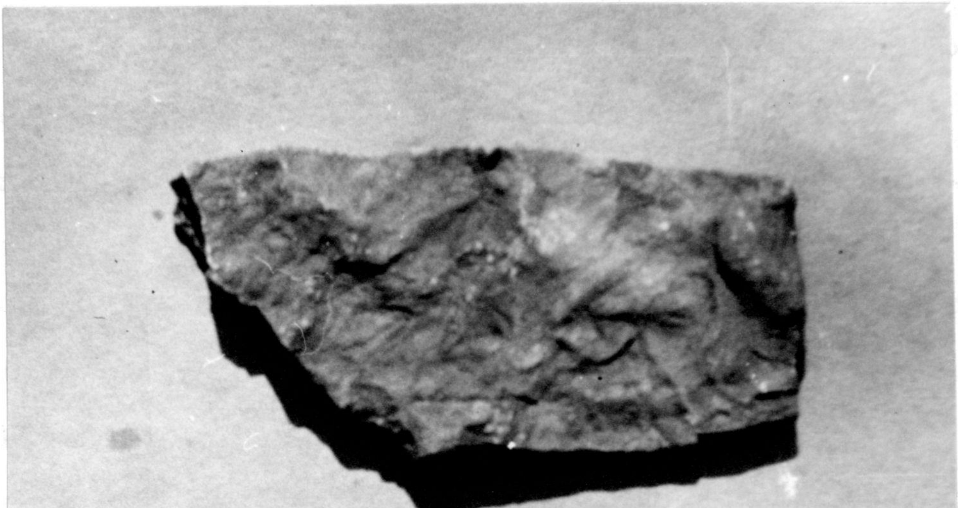


Plate 5.—Hand specimen of Pioche shale, showing characteristic worm(?) tracks and trails.

Lithologic and stratigraphic correlation can probably be made with the Cambrian shales present in the Cricket Mountains. Faunal or biostratigraphic correlation, as previously indicated, can be made with the Ophir shale in the Oquirrh Mountains.

Undifferentiated Cambrian Limestones

Lithology. The undifferentiated Cambrian limestone which conformably overlies the Pioche shale, is medium to dark gray, and weathers buff and medium and dark gray. The limestone is massive and thick bedded where bedrock exposures are encountered, but the bedding is quite irregular in places. In part, the limestone has been silicified and dolomitized. The texture is fine to medium crystalline. Numerous calcite veinlets traverse the rock in haphazard fashion. Iron staining, probably hematite, occurs along joint planes.

Age and correlation. No identifiable fossils were found in the undifferentiated Cambrian limestone, and exact age determination was not possible. However, these rocks lie conformably above the Pioche shale which contains Middle Cambrian fossil fragments, and therefore are believed to be late Middle Cambrian or early Upper Cambrian in age.

Once again, on the basis of lithologic similarity and stratigraphic sequence, correlation may be possible with the Cricket Mountains exposures.

Measured section. The following section of undifferentiated Cambrian limestone was measured in the northeast quarter, Sec. 23, T. 25 S., R. 10 W. The limestones are unconformably overlain by Cretaceous(?) conglomerate.

	Feet
Cretaceous(?)-Indianola conglomerate:	
Cambrian-Undifferentiated limestone:	
Unit 10. Limestone; medium to dark gray, weathering light gray and buff, fine to medium crystalline, massive to thick bedded, (bedding irregular). Iron stains, calcite veinlets, silicification, and dolomitization present.	123
Unit 9. Limestone; fresh color as in #10, weathering medium to dark gray, texture and secondary features as in #10. Few good exposures, much float.	65
Total measured thickness of exposed undifferentiated Cambrian limestone..	188

A thicker section of undifferentiated Cambrian limestone (about 500 feet) is exposed as part of the metamorphic aureole which defines the major igneous-sedimentary boundary. This section was not selected for detailed measurement and description owing to its metamorphosed character. However, field and petrographic descriptions of this aureole are presented under the section on metamorphic zones.

Cambrian(?) System

As shown on the accompanying geologic map, most of the sedimentary division of the Northern Mineral Range is represented by a limestone which the writer has tentatively classified as being Cambrian(?) in age.

The limestone underlies quartzite which constitutes the lower part of a probable thrust plate, and which is probably the Lower to Middle Cambrian Prospect Mountain quartzite. This Cambrian(?) limestone is lithologically similar to the previously discussed undifferentiated Cambrian limestone which conformably overlies the Pioche shale at the north and south ends of the sedimentary division. However, it was not possible to precisely correlate the two units because: (1) no identifiable fossils were discovered in either of the limestone units; (2) the base of the Cambrian(?) limestone is nowhere exposed; and (3) metamorphism has altered some of the original lithologic characteristics of the rocks.

The contact between the Prospect Mountain quartzite and the Cambrian(?) limestones shows no marked disparity in the attitudes of the two units, and no mylonite zone nor brecciated zone was found at the contact by the writer. However, a tabular lamprophyric body, about 12 feet thick, is locally present between the limestone and quartzite. These, and other criteria concerning the existence of a Northern Mineral Range overthrust are discussed in detail in the section on structure.

Cambrian(?) Limestone

Lithology. The limestones are remarkably uniform in their lithologic character, except in the vicinity of fault zones and near intrusive rocks where they have been dolomitized, silicified, and tremolitized to varying degrees.

In general, the Cambrian(?) rocks are dark gray, and weather light, medium, and dark gray. The variation in weathering color has resulted in a marked banded appearance of the unit in general. The lighter bands vary in width, ranging from 3 inches to more than 20 feet. Where the limestone is massive and thick bedded it forms ledges, and comprises talus slopes where it is thinner bedded and/or where it is part of a fault zone. The limestone is finely crystalline, except where metamorphism has effected a local coarsening of texture.

Chert lenses are abundant in the limestone, and are generally concentrated in the lighter gray units (See Plate 6). There is an increase in number and size of these lenses upward through the section. The chert lenses range up to one foot or more in length, and are several inches wide in places. Chert nodules are not uncommon, and are exceptionally abundant locally. Calcite veinlets are numerous, and barite veins and iron stained rocks are common. The barite veins are restricted to areas of fracture, and the iron staining is predominant along bedding planes.

Plate 6.—Chert lenses in lighter gray bands of variable widths, within the Cambrian(?) limestone. Field notebook 7 inches long.

Age and correlation. The crux of the problem involving the sedimentary rocks of the Northern Mineral Range lies in the positive dating of this limestone, which underlies the probable Cambrian Prospect Mountain quartzite, as this could conclusively prove the existence of an overthrust in the Northern Mineral Range.

The limestone was found to be unfossiliferous, and the few fossil fragments which were collected were unidentifiable. Therefore, correlation and age determination on the basis of biostratigraphy was not possible. In addition, the base of the limestone is not exposed and the top is abruptly terminated by the probable thrust plate. Therefore, correlation based on stratigraphic sequence is not possible. (It is acknowledged by the writer that there are several limestone-quartzite sequences present in the geologic column in the western interior. The most similar of these is the Ordovician Pogonip-Eureka sequence. However, this is not believed to be the sequence in the Northern Mineral Range, and evidence disfavoring this normal succession is presented in the section on structure.)

In view of the above, and keeping in mind the fact that every rock unit represents the record of a definite depositional environment, it has been necessary to attempt correlation with other areas within the confines of the same depositional basin. Correlation is then based on the combination of lithologic identity, structural relationships, and time-rock relationships (such as position in the bathymetric cycle).

The San Francisco Mountains, located about 20 miles to the west, is the area with which the writer has decided to attempt correlation. This region has recently been studied by East (1957), and prior to that by Butler (1913). Moreover, this area was selected because: (1) in Early Paleozoic time the San Francisco Mountains belonged within the same depositional basin (geosyncline) as the Northern Mineral Range; (2) the two areas exhibit similar lithologies and metamorphic affects, and also appear to be related structurally; (3) the Ranges are only 20 miles apart; and (4) age determinations of the rocks in the San Francisco Mountains have been based on paleontological evidence in combination with lithologic identity.

East has designated more than 3,000 feet of cliff-forming carbonate rocks as being Middle(?) and Upper Cambrian in age, chiefly on the basis of scanty fossil evidence and the light and dark banded appearance of the fairly uniform strata typical of the Cambrian formations in the Great Basin. In addition, the rocks have been dolomitized and tremolitized, similar to the limestones in question in the Northern Mineral Range. Moreover, both areas have probably been subjected to overthrusting, probably at about the same time and involving generally similar rocks, all of which suggests perhaps a relatively similar tectonic history. Finally, the carbonate sequences of each area are representative of long-continued deposition with unbroken successions of strata, and owing to their uniform lithology, paucity of fossils, and thicknesses (greater than 1,000 feet in the Northern Mineral Range), they are indicative of deposition in a moderate to deep sea, or at least occupy approximately the same position in the bathymetric cycle.

The writer has visited the San Francisco region, and is of the opinion that the limestone underlying the quartzite in the Northern Mineral Range is the approximate age equivalent of the Middle(?) and Upper Cambrian limestone described and dated by East.

If this is presumed to be so, it would indeed support the hypothesis of a thrust in the Northern Mineral Range.

Dr. L.F. Hintze* (personal communication) recently informed the writer that the hills just north of Black Rock, which is located less than 15 miles northwest of the north end of the Mineral Range (See Fig. 2), are partly comprised of Cambrian limestones as he had collected some fossils from them. The writer has briefly visited the area, and has found strata which are lithologically similar to the limestone in question in the Northern Mineral Range.

Furthermore, Hintze also confirms the exposure of Cambrian carbonate rocks in the San Francisco Mountains, as well as indicating their presence in the nearby Cricket and Wah Wah Mountains.

In view of all of the above mentioned information, the most logical choice for age assignment for the limestones, on a regional basis, must be Middle(?) and Upper Cambrian.

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* Dr. L.F. Hintze has done considerable work concerning the Ordovician stratigraphy of western Utah, and is undoubtedly one of the leading authorities on the problems which exist in differentiating Cambrian from Ordovician carbonates throughout the Great Basin area. A published example of one of his more recent studies on this subject has been included in the bibliography. Dr. Hintze is presently associated with the department of geology at Brigham Young University.

Conditions of deposition. Based on information presented in a paper by Krumbein and Garrels (1952), the writer believes the Cambrian(?) limestones were probably formed through chemical processes in relatively quiet moderate-depth marine waters with open circulation. Reasons for the existence of this type of sedimentary environment during a part of Early Paleozoic time are listed below:

(1) The Cambrian(?) limestone is of a thickness probably greater than 1,000 feet; it is massive and thick bedded for the most part; and it is a fine to medium crystalline deposit of general uniform lithology.

(2) The limestone is decidedly unfossiliferous.

(3) There is an absence of the more soluble evaporites such as gypsum and anhydrite.

According to Krumbein and Garrels, limestones of this description should be deposited under specific conditions of pH, Eh, and concentration (salinity),and these, in fact, define the particular sedimentary environment.

Dolomitization. No distinct dolomite beds of any significant thickness or continuity were found to exist in the Northern Mineral Range. However, Cambrian limestones have locally undergone irregular dolomitization. The conversion of limestone to dolomite could have been produced by hydrothermal solutions related to the igneous body which is exposed to the south, and possibly to an igneous body which may be subjacent to the central part of the sedimentary division.

The primary factor which controls the extent of dolomitization is probably the faulting which has occurred in the area, rather than bedding planes or original composition of the rock. Owing to the predominance of unaltered normal marine limestone in the area away from major fault zones, it is not unreasonable to suppose that most, if not all, of the original deposit was limestone. There also exists the possibility that dolomitization was affected in more than one stage, and that this process preceded the formation of the ore deposits in the area. Solution of the problem is beyond the scope of this report, and the necessary chemical analyses and petrographic study are suggested for future investigation. In the Tintic district, Utah, a similar situation may exist (Payne, 1950), and the reader is referred to the discussion of hydrothermal dolomitization of Cambrian sediments which is presented therein.

<u>Chertification</u>. As mentioned previously, chert is especially common to the limestones in the Northern Mineral Range, and occurs mainly as lenses and nodules.

The lenses definitely follow stratification and are generally peculiar to the lighter gray weathering units. According to Pettijohn (1957), this concentration of chert in certain layers, parallel to the bedding, may indicate that the beds are susceptible to replacement and therefore the lenses are of a postdepositional origin. Pettijohn also states that these same field relations indicate that the chert is unrelated to the present-day surface and processes of weathering, but to the sedimentation responsible for the host rock itself. The chert nodules do not follow any definite zones or planes in the limestone. More conclusive proof of a replacement origin, such as the presence of irregular patches of limestone within some chert lenses, was not discovered by the writer. The solution of the chert problem in the Northern Mineral Range, as that of the dolomite, is beyond the scope of this report. For a good résumé of the evidence bearing on the question of the origin of chert and dolomite, the reader is referred to the papers by Van Tuyl (1916, 1918).

<u>Measured section</u>. The following section was measured in the northwest quarter, Sec. 26, T. 25 S., R. 10 W. Owing to the remarkable similarity in the lithologic character of the limestone, units were designated chiefly on their differences in outcrop expression.

Cambrian-Prospect Mountain quartzite: Cambrian(?)-Undifferentiated limestone:		Feet
Unit 20.	Partly covered limestone talus slope, few ledges, upper 50 feet covered by quartzite talus; dark gray, weathering light to dark gray, finely crystalline. Chert lenses in lighter gray units more than one foot in length.	487
Unit 19.	Covered limestone talus slope; color and texture of fragments as in #20. Chert nodules locally abundant.	270
Unit 18.	Limestone; bedding regular and light gray weathering bands narrow; color, texture, as in #19 and #20. Chert lenses and nodules common; iron staining along bedding planes.	107
Unit 17.	Limestone; massive, forms a ledge; color and texture as in above units. Chert lenses up to 1 foot in length and 2 to 3 inches in width.	28

Measured section (contd.)	Feet
Unit 16. Limestone; lithology and outcrop expression as in #17, but light gray bands narrower and range in width from 3 inches to 2 feet. Chert lenses common, but of smaller dimensions than those in #17.	55
Unit 15. Covered limestone talus slope; lithology as in above units.	125
Unit 14. Limestone; lithology and outcrop expression as in #16. Black chert nodules make up 10% of rock in places.	21
Unit 13. Covered limestone talus slope; lithology as in above units.	130
Unit 12. Limestone; massive, forms a ledge; fresh and weathering color is dark gray, texture as in #20. Calcite veinlets common as in most of above units.	23
Unit 11. Limestone; medium to thin bedded, bedding wavy; lithologically similar to above units, but this unit is distinctly mottled. Chert lenses sponge-like.	15

Total measured thickness of Cambrian(?) limestone........1285

Cretaceous(?) System

The only sedimentary rocks exposed in the area mapped, which may be of Mesozoic age, is a conglomerate which rests unconformably on the undifferentiated known Cambrian limestones near the north end of the Range. This unfossiliferous formation is given a tentative Cretaceous(?) age assignment on the basis of lithologic similarity and approximate stratigraphic position relative to rocks of known age. It is correlated with the Indianola(?) conglomerate which overlies Late Cambrian sediments in the Canyon Range, Utah (See Fig. 2).

In the Central Mineral Range, Earll (personal communication) reports a conglomerate which he has tentatively classified as Cretaceous(?) in age. The conglomerate overlies the Moenkopi (Triassic) formation, and is in turn overlain by a volcanic sequence of questionable Middle Tertiary age. Earll has correlated this conglomerate with the Claron conglomerate exposed in the Iron Springs district near Cedar City(See Fig. 2). No evidence has been discovered by Earll in the conglomerate of the Central Mineral Range, which warrants precise correlation with the Indianola(?) conglomerate of the Northern Mineral Range. Therefore, at the present time, the relationship between the two conglomerates is uncertain.

Indianola(?) Conglomerate

Lithology. The Indianola(?) conglomerate exposed in the Northern Mineral Range is composed mainly of limestone fragments. However, quartzite fragments and black chert nodules are common, and a few sandstone fragments are present. The limestone components are gray to blue; the quartzites are shades of gray; and the sandstone fragments are generally light brown. The fragments range in size from 2 mm. to 256 mm. in diameter, or from granules through cobbles. They are subrounded to subangular. The matrix is a well cemented limestone, which is generally similar in color to the limestone fragments, but in places is stained red-brown. The conglomerate is massive and forms ledges (See Plate 7).

Age and correlation. As previously indicated, the conglomerate is thought to be Cretaceous(?) in age, and is correlated with the lower part of the Indianola(?) conglomerate in the Canyon Range.

According to Christiansen (1951), the lower unit (800 feet) of the Indianola(?) Group in the Canyon Range consists predominantly of limestone pebbles and cobbles. Overlying this unit is a massively bedded quartzite cobble and boulder conglomerate (1800 feet), and an upper unit (9000 feet) which consists of conglomerates interbedded with sandstone, shale, and limestone members. In addition, in the Canyon Range, the Indianola(?) Group lies unconformably on Cambrian sediments, as does the conglomerate in the Northern Mineral Range.

Other Mesozoic and Cenozoic conglomerates (Price River, Pool Creek) which crop out in East and Central Utah, are described by Christiansen and Spieker(1949). These appear to be lithologically dissimilar to the conglomerates of the Northern Mineral Range, on the basis of predominant type and size of fragments and type of matrix.

<u>Measured section</u>.The section was measured in the northeast quarter, Sec. 23, T. 25 S., R. 10 W. Differentiation into 4 distinct units was possible, based on predominating fragment size.

<u>Cretaceous(?)-Indianola(?) conglomerate</u>:	Feet
Unit 24. Conglomerate; predominantly gray to blue limestone fragments, gray quartzites and black chert nodules common; forms a ledge; mostly pebbles with few lenses of cobble size. Well cemented gray to blue limestone matrix.	21
Unit 23. Conglomerate; lithology except particle size as in #24; fragments of cobble size (64mm. to 256mm.).	23

Measured section (contd.)	Feet
Unit 22. Conglomerate; same lithology, but fragment size as in #24. Few sandstone fragments noted.	20
Unit 21. Conglomerate; same lithology as above units, except texture is granulose (2mm. to 4mm.) and sand grains more common.	48

Total measured thickness of Cretaceous(?) Indianola(?) conglomerate..112

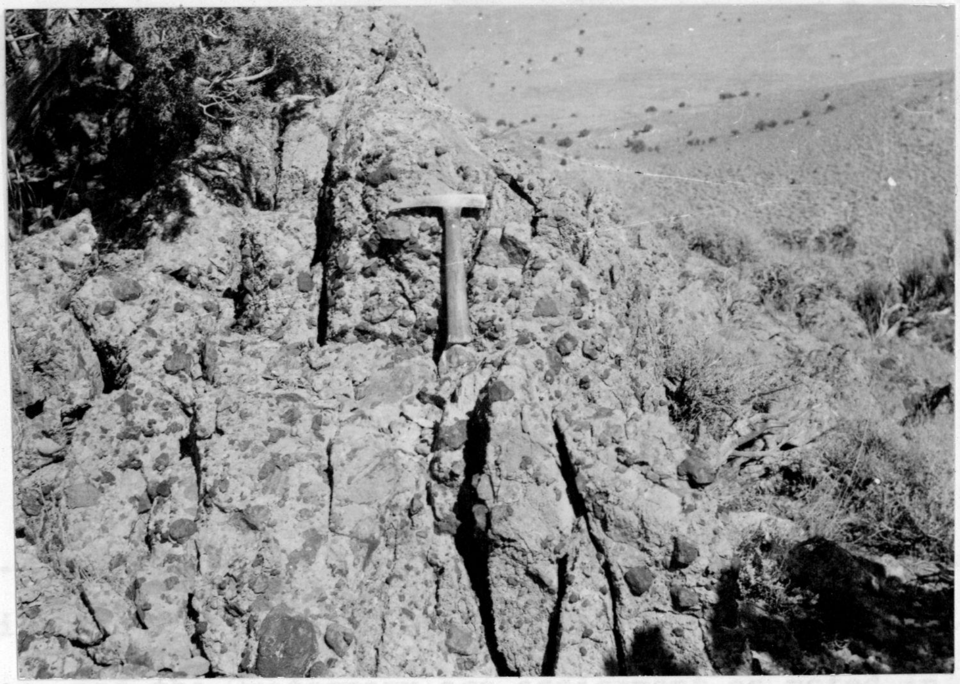

Plate 7.—Indianola(?) conglomerate near north end of Range. View is northeastward. Note massive, fractured character and relative particle sizes. Constituents are mostly limestone and quartzite.

Quaternary Deposits

<u>Lake limestone</u>. Isolated patches of lacustrine limestone crop out west of the Northern Mineral Range on the valley plain. One of these is less than a mile northwest of Lead Canyon, and is partly covered by Recent basalt flows (See Plate 8 and Fig. 1).

About 2 miles west-southwest of this outcrop is an exposure of similar limestones which is the site of two wells, drilled in 1930 by the Beaver Valley Oil Co. Records of the wells reveal Quaternary deposits to a minimum depth of 3,500 feet.

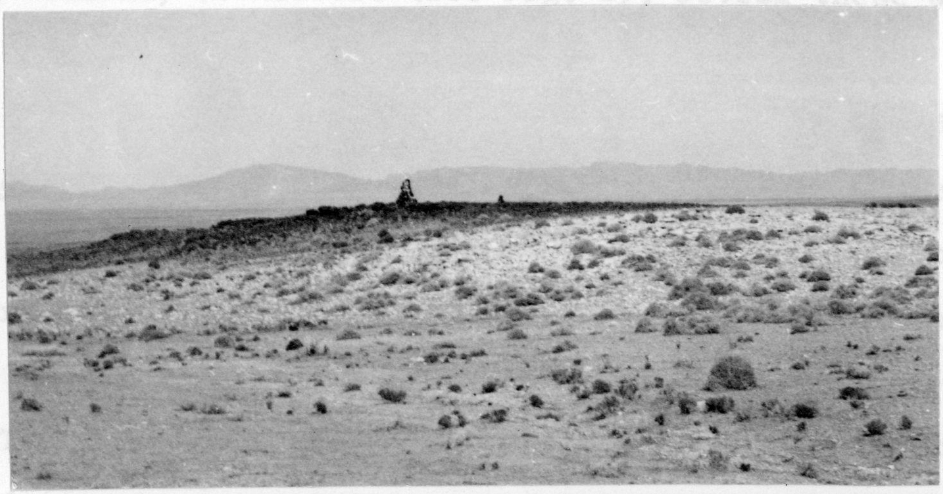

Plate 8.-Quaternary(?) limestone exposure, overlain by black, Recent basalt flows. View is northwestward. Cricket Mountains in background.

The exposed limestone is cream colored and finely crystalline. Limited petrographic examination reveals more than 90% calcite and a few quartz grains. No fossils were found by the writer, and the Quaternary age assignment as noted in the well records cannot be confirmed. It is not unreasonable to suppose that the limestones may be older, possibly Tertiary in age, and thus the Quaternary age classification is questionable.

Shore deposits. The highest stage of Lake Bonneville barely touched, if at all, the eastern and western sides of the Northern Mineral Range.

However, exposed on the valley plain, where not covered by Recent alluvium or basalt flows, are spits and bars delineating the general shore zone of Lake Bonneville. These features are more readily observable on aerial photographs than from the ground.

Information obtained from well records (Lee, 1908), in the vicinity of Milford (See Fig. 2), reveal these deposits to be alternating beds of unconsolidated sand, gravel, and clay, and which have a total minimum thickness up to 750 feet.

Talus debris. The group of colluvial talus deposits present in the area mapped includes the rock detritus which occurs in the form of slides and streams, and even a general talus mantle upon occasion.

The Prospect Mountain quartzite, eroded and faulted extensively, has especially resulted in the development of these type deposits. In fact, the quartzite talus debris which covers most of the quartzite-limestone thrust contact has unfortunately made close examination exceedingly difficult.

Consolidated gravels. Near the southern end of the area, immediately west of the Range, is a fairly large outcrop of consolidated gravel. It is comprised mainly of fragments of igneous rock, and the cementing material is lime and silica. Other outcrops of material derived from the granitic mass occur in places close to the base of the Range, but have not been mapped owing to their small size.

Alluvium. A long period of emergence has resulted in the building up of large alluvial fans at the base of the Range. The character and composition of the material is controlled by the nature of the rock of which the Range is composed and the distance therefrom. Alluvium also covers much of the valley plain.

IGNEOUS ROCKS

General Statement

The igneous rocks exposed in the Northern Mineral Range constitute a heterogeneous assemblage, and are comprised of plutonic, volcanic, and hypabyssal types. They are generally confined in exposure to the southern two-thirds of the area mapped. Granite constitutes the bulk of the igneous rocks. A granodiorite body forms the boundary at the north end of the granite. A series of well defined porphyritic quartz latite dikes, and two rhyolite porphyry volcanoes are present within the plutonic rocks. Basalt flows, and basic, aplitic, and pegmatitic dikes crop out to a lesser extent in the area. A lamprophyre dike was found to exist at the Cambrian Prospect Mountain quartzite-Cambrian(?) limestone thrust contact in the northern third of the area (See geologic map Fig. 1).

All of the igneous rocks have been systematically classified on the basis of field observations and limited microscopic examination. Therefore, since nomenclature is usually based on relative percentage of minerals within an igneous rock, and slight variation of these percentages actually warrant different rock names, a more thorough microscopic study may result in some slightly different igneous rock classifications.

Plutonic Rocks

Granite

Field and petrographic description. The exposed granitic mass comprises the main part of the Range. Its northern boundary is approximately one mile north of Pinnacle Pass, and it extends southward into the Central Mineral Range, a distance of about 15 miles. The greatest dimension of the granite in the area mapped is from north to south, its small end pointing north.

The granite comprises an area of slightly less than 20 square miles in the Northern Mineral Range, but to the south reaches larger exposed dimensions where it is about 50 square miles in aerial extent (Earll, personal communication). However, regardless of these accepted batholithic proportions, the granite has been referred to as a stock. This has been due to: (1) the Mineral Range granite is of much smaller dimensions than the known batholiths of the western United States, such as the Sierra Nevada and the Idaho batholiths, and (2) the granite could be composed of several stock-like intrusions, rather than one of batholithic proportions, although no evidence was discovered to confirm this possibility.

The granite could be larger than the 70 square miles which is exposed in the Mineral Range, as an alluvium-mantled granitic pediment apparently forms the slopes which flank much of the Range on both the west and east sides.

The granitic body in the area mapped forms ridges and spurs which project outward from the main mountain mass. These ridges trend in general east-west, almost perpendicular to the main axis of the Northern Mineral Range, and are separated by numerous canyons and valleys. From a distance, the granite is seen to form massive, heavily jointed outcrops, and bold peaks are common (See Plate 9). The color of the granite ranges from medium to light gray along the western margin and adjacent to the granodiorite on the north. In the interior, the granite is generally lighter colored, being nearly white in places.

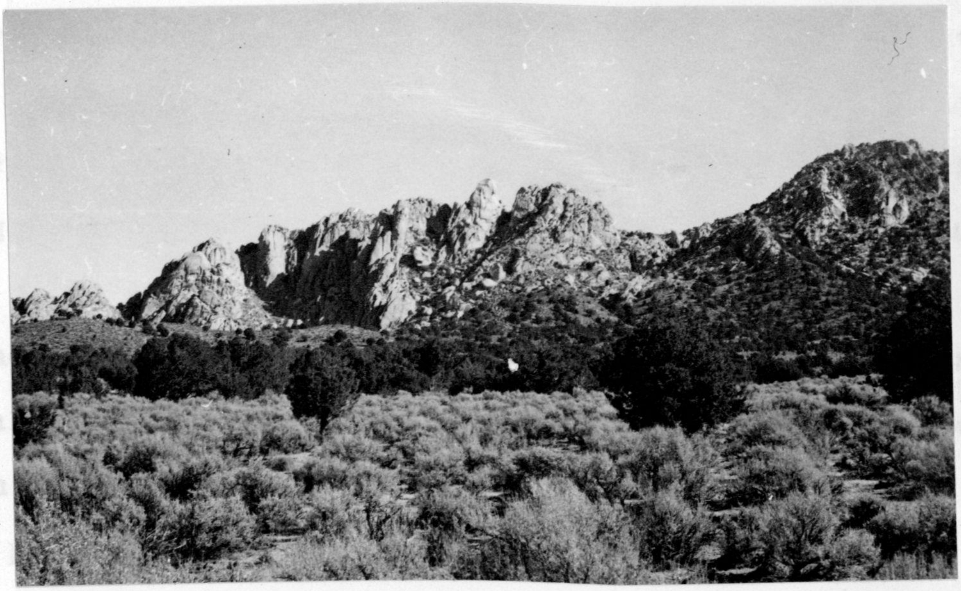

Plate 9.-View looking east at granite outcrop, which is representative of massive, jointed exposures in the Northern and Central Mineral Range.

Hand specimen examination reveals a coarse (5 mm. to 3 cm. in crystal diameter) equigranular rock composed chiefly of feldspar and quartz, and subordinate amounts of ferromagnesium grains. Earll and the writer have noted slight changes in composition in several specimens collected from the granite in the Central and Northern Mineral Range which actually warrant classification under other rock names. These "facies", however, were not separated on the map because it was generally not possible to make positive distinctions in the field.

Three specimens considered typical of the granitic mass were selected for microscopic examination which shows that potash feldspar (orthoclase and microcline), the most abundant minerals, comprise about 50% of the rock. Quartz (15% to 20%), oligoclase (10% to 15%), and biotite (5% to 10%) make up the remaining essential minerals (those present in amounts greater than 5%). Magnetite, sphene, and a few crystals of apatite are present in accessory (less than 5%) amounts. Chlorite and sericite are the chief alteration products, from the biotite and oligoclase, respectively, and are present in amounts up to 10%.

The texture is typically hypautomorphic-granular, and the subhedral and euhedral feldspar and biotite generally exceed 5 mm. in diameter. The quartz occurs in clear, anhedral, interstitial patches (See Fig. 4 in pocket).

<u>Age and correlation</u>. From field evidence it can only be shown that the granite is post-Permian and pre-Late(?) Tertiary in age. Earll confirms clear cross cutting relationships between the granite and Permian sediments in the Central Mineral Range. Two rhyolitic volcanoes are situated on top of the granite in the Northern Mineral Range, and as will be shown later, are probably Late Tertiary in age. In order to postulate a more precise age for the granite, it is necessary to examine adjacent areas which have been subjected to similar intrusive activity.

Callaghan (1938), in his study of the alunite deposits of the Marysvale Region, Utah, recognizes two divisions of volcanic rocks in the Tushar Mountains (See Fig. 2). The oldest volcanic sequence is believed to be Early Tertiary in age, and subsequently has been warped, faulted, and intruded by quartz monzonite magma. The intrusion on the other hand, appears to be older than the younger volcanic sequence which is Late(?) Tertiary in age. In short, Callaghan is of the opinion that the quartz monzonite intrusive is Middle Tertiary in age, although evidence is indirect and not conclusive.

To the west in the San Francisco Mountains (See Fig. 2), East (1957) has dated the quartz monzonitic intrusion as being late Early to Middle Tertiary in age, based primarily on the fact that it cuts volcanic rocks of probable Late Oligocene age.

Mackin (1947) refers to Butler (1920) who has summarized indirect evidence indicating that Tertiary latitic lavas predate the intrusions in the Iron Springs district, located about 40 miles south of the San Francisco district and west of Cedar City.

A look at the regional picture reveals more indirect evidence that, in general, the intrusions in western Utah are Tertiary, and those farther west are considered to be Late Mesozoic.

In view of the above, the writer has tentatively classified the granitic mass in the Northern Mineral Range as Middle Tertiary in age.

Granodiorite

Field and petrographic description. The granodiorite of the Northern Mineral Range bounds the large granitic mass on the north (See Fig.1). The northern boundary of the granodiorite is in relatively sharp contact with the Cambrian limestones and shales which form the well defined marble-hornfels zone. As exposed in this area, the granodiorite is less than 2 square miles in areal extent. However, granodiorite inselbergen are found a short distance west of the Central Mineral Range (Earll), as well as in the area mapped in this report, and consequently the granodiorite may be much larger.

Therefore, with consideration also of the granite, it seems logical to presume that the plutonic rocks of the Mineral Range may exceed 100 square miles in total area.

The granodiorite, in general, is exposed on a surface of lower relief when compared to the granite which, as previously indicated, is characterized by its numerous massive pinnacles and projecting ridges and spurs. It is this feature which causes the granodiorite to be easily distinguishable from the granite at any appreciable distance from the Range (See Plate 10).

Hand specimen examination reveals the granodiorite as a medium to dark colored, equigranular rock of medium grain size. Feldspar and ferromagnesium minerals are the predominant components, and a little quartz is noticeable.

Under the microscope two thin sections of granodiorite were seen to contain plagioclase (oligoclase) in amounts exceeding 30% of the total mineral composition. Alkali feldspars (microcline and orthoclase) comprise about 20% of the rock, and quartz (10%), hornblende (10%), and biotite (5% to 10%) make up the remaining essential minerals. Magnetite, sphene, and apatite are the chief accessory minerals. As in the granite, sericite and chlorite are the main secondary alteration products, present in accessory amounts, and altered from the hornblende, biotite, and feldspars.

The texture is hypautomorphic-granular, and most of the essential minerals are greater than 1 mm. in diameter. The biotite and hornblende tend to be euhedral; the feldspars subhedral to euhedral; and the quartz grains anhedral and interstitial. The magnetite, as in the granite, forms primary euhedral grains as well as secondary anhedra (See Fig. 5).

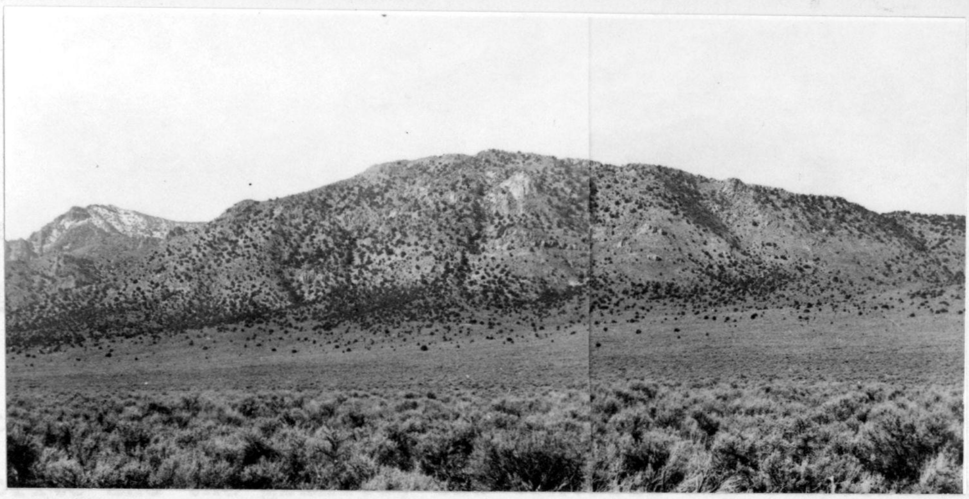

Plate 10.-View looking west, showing entire granodiorite exposure. Higher and more massive granite outcrops are visible in the background near the left margin of the photograph. Linear elements within the granodiorite are quartz latite dikes.

Relationship to granite. The northernmost granite-granodiorite contact has been observed to be gradational up to a distance which exceeds 50 yards. To the north lies the medium grained granodiorite; to the south, the coarse granite; and between the two an uninformative area of erosion (canyon) or a fine grained facies. Certainly no sharp plutonic contacts have been observed comparable to some of those depicted by Hamilton (1956) in the Sierra Nevada area. In view of the above, it was necessary to arbitrarily draw the contact as a dashed line (See geologic map).

As previously indicated, several granodioritic inselbergen are exposed along the western margin of the Northern and Central Mineral Range. Eastward of these inselbergen, on the western flank of the Range in contact with the granite, are exposed numerous patches of granodioritic, dioritic, and gneissic rock which exhibit metamorphic as well as igneous features to varying degrees. This zone has been described in the section dealing with metamorphic rocks, under the subheading "basic zone". It is briefly mentioned here since part of the zone could be related to the granodiorite discussed above.

Age of the granodiorite. The granodiorite could represent an episode of magmatic differentiation distinct from a later granitic phase. The areal extent and type of exposure of the granodiorite and the granite, and textural and compositional differences of the two, are the most significant and visible evidences which indicate this possibility. If this is presumed to be so, then the granodiorite is possibly Early Tertiary in age.

Perhaps, of special interest are the granodioritic to dioritic stocks which Butler (1913) has mapped in his study of the San Francisco Region. These bodies are exposed within and near the Rocky Range, about 7 or 8 miles east of the San

Francisco Mountains. The granodiorite contains intrusive bodies of quartz monzonite, a rock indicated as being Late Eocene to Miocene in age. The granodiorite is the older rock, according to Butler, and if this is so, it may be related in age to the granodiorite of the Northern Mineral Range.

Inclusions in the Plutonic Rocks

Inclusions are relatively common in the granitic mass, but moreso on the margins than in the interior. They are medium to dark gray in color, fine grained, and of granodioritic composition in general, thus similar to the inclusions described in the metamorphic section concerning the basic zone. The inclusions are generally of hand size, but in one particular locality (Cabin in the Rock), about 1½ miles west of the larger rhyolitic volcano, they were observed to reach several feet in diameter (See Plate 11).

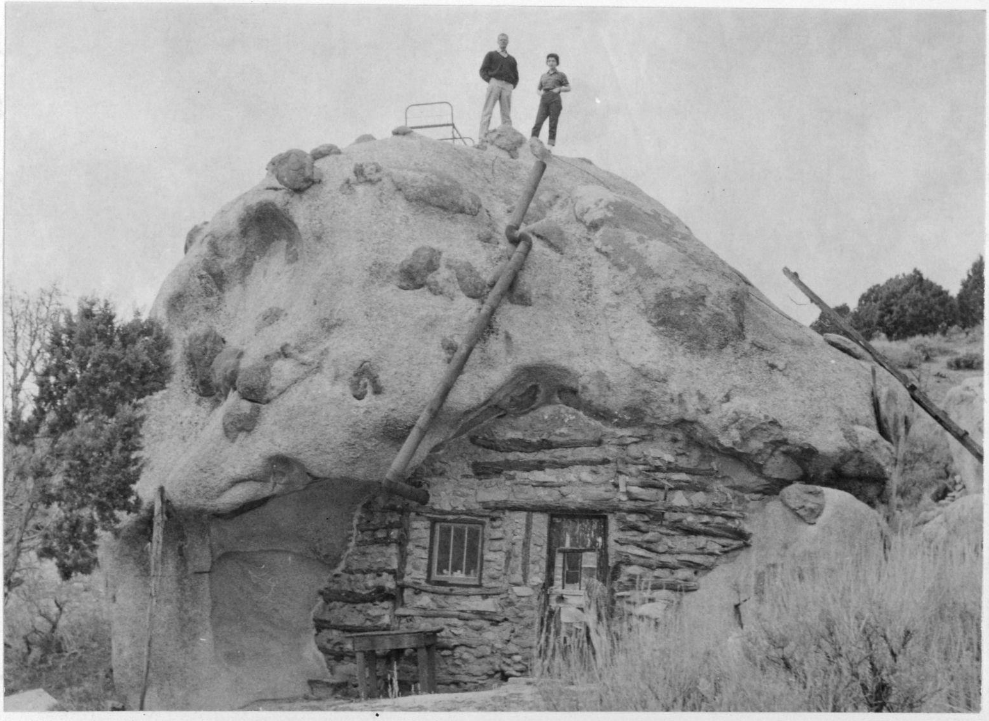

Plate 11.-"Cabin in the Rock". Photograph shows large, disoriented inclusions in granite. Writer's wife is 5 feet 3 inches tall.

The inclusions in the granodiorite are darker, fine grained, and more basic in composition. They are rarer than those within the granite, and everywhere were observed to be of hand size or less.

The only areas where inclusions were observed to be oriented were in the narrow transitional zones between the granite and basic rocks. These zones shall be treated more fully in the section on metamorphic rocks.

Origin of the Plutonic Rocks

Examination of products of processes has led the writer to believe that the plutonic rocks of the Northern Mineral Range are chiefly of magmatic origin. This opinion is based on the following: (1) physical displacement of the sediments on the eastern margin of the Central Mineral Range (Earll, personal communication), and in the vicinity of the tremolitized zones in the Northern Mineral Range; (2) development of well defined contact metamorphic aureoles in both the Northern and Central Mineral Range; (3) presence of abundant disoriented inclusions; (4) evidence suggestive of granitization, as will be shown later, is restricted to local areas along the western margin of the granitic mass, thus it is only natural to assume the possibility of major magmatic emplacement; and (5) the granodiorite-granite mass(es), quartz latite dikes, and rhyolitic volcanoes (each younger than the other) indicate a normal crystallization process of differentiation from a magma.

The ultimate source of the probable magmatic plutonic assemblage is perhaps one or a combination of more than one of the following: (1) primary acidic magma; (2) differentiation of primary basic magma; or (3) remobilization (rheomorphism) of a primary granitic crust. Owing to inadequate information concerning the problem and its solution, it is not possible to even conjecture any one hypothesis.

Volcanic Rocks

Rhyolite Porphyry

Field and petrographic description. The rhyolite porphyry is exposed only in the southern part of the area, within the main granitic mass, and is represented by two volcanic cones (See Plate 12). Specifically, they are located in sections 24, 31, and 32, T. 26 S., R. 9 W. These cones form the northernmost components of a series which extends, in a relatively linear trend, generally southward into the Central Mineral Range (Earll, personal communication). Of special interest is the easily accessible rhyolitic cone which is located about 6 miles north-northeast of the Mineral Range, well beyond the area mapped in this report. This cone has been referred to as the "Black Rock Volcano", and has been noted as such on various maps of Utah. However, upon closer observation, the cone is seen to be comprised of rhyolite, with Recent basalt flows lapped up against part of its exposed base (See Plate 13). Megascopic examination reveals that the "Black Rock Volcano" is similar in general composition and appearance to the rhyolite porphyry cones exposed in the Northern Mineral Range, suggesting perhaps that they are all part of a volcanic series which was extruded at

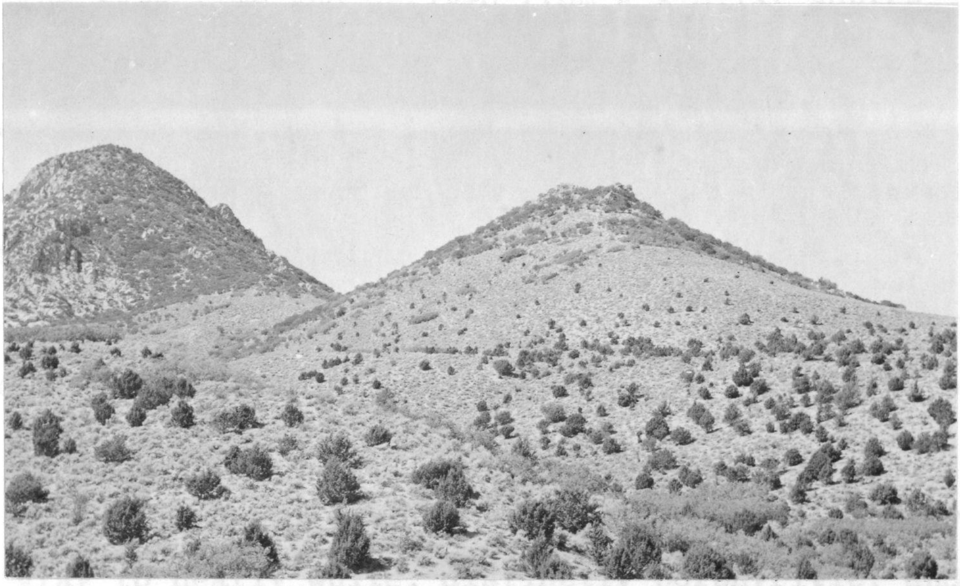

Plate 12.—Larger and better preserved of the two rhyolite porphyry volcanoes within the granite of the Northern Mineral Range. View is westward.

Plate 13.—View, looking northward, of "Black Rock Volcano". Photograph shows dark basalt flows overlying part of exposed base of volcano, which is of general rhyolitic composition and similar to those within the Northern Mineral Range.

about the same time and derived from a similar source.

The larger, and better preserved of the two volcanic cones exposed in the Northern Mineral Range is about 350 feet high; approximately 3,000 feet in diameter across its exposed base; and about 450 feet in diameter across the crater. The smaller, and more easterly cone, has been breached and only part of the crater remains preserved. The slopes of the cones are about 25°.

Hand specimen examination reveals the rhyolite to be light gray to nearly white, distinctly porphyritic, and containing phenocrysts of quartz and feldspar. Dark minerals appear to be almost entirely absent, and because of this, a hand specimen may be distinguished from the porphyritic quartz latite dike rocks, described later. The groundmass is microcrystalline.

Under the microscope, the rock is seen to contain anhedral and subhedral phenocrysts of quartz, orthoclase, sodic plagioclase, and less than 2% of bleached biotite and iron ore. The quartz and feldspar phenocrysts comprise about 25% of the rock. The groundmass shows incipient intergrowths of quartz and feldspar (See Fig. 6).

<u>Age</u>. The two volcanoes are clearly younger than the granite in which they are situated. The writer believes they are not older than Late Tertiary in age because: (1) they are well preserved, in fact the larger of the two has retained its crater completely, and therefore has not undergone a very long period of erosion; and (2) they are similar in composition to

the Late(?) Tertiary volcanics which Callaghan (1938) has described in the Marysvale area to the east, in the vicinity of the Tushar Mountains (See Fig. 2).

Basalt

Field and petrographic description. Basalt flows overlie the valley plain east of the Range, and can be traced to the volcano at Cove Fort, just west of U.S. Highway 91 (See Fig. 2 and Plates 14 and 15). Basaltic lavas also flowed around the north end of the Range, and are exposed in patches along the northeast and northwest sides. Two distinct outcrops overlie the granite and sedimentary rocks on the eastern margin of the range proper, and may indicate the location of a postulated Basin and Range border fault.

The rock is a typical porphyritic black basalt, and phenocrysts of pyroxene and plagioclase are distinguishable in hand specimen examination. At all exposures encountered, the rock had a sponge-like or vesicular appearance owing to the abundance of gas cavities. The groundmass is microcrystalline.

Microscopic examination reveals that phenocrysts of labradorite and augite make up 40% of the rock, and a few olivine crystals are present. The groundmass consists of interstitial labradorite laths mixed with augite and some glass. Magnetite is the most common accessory mineral.

The phenocrysts range from .5 mm. to more than 1 mm. in diameter, while the crystals of the microlitic groundmass are about .1 mm. in diameter (See Fig. 7).

Plate 14.—Cove Fort volcano, located about 10 miles east of the Mineral Range, part of which is seen in the background near the right edge of the photograph. View is southwestward.

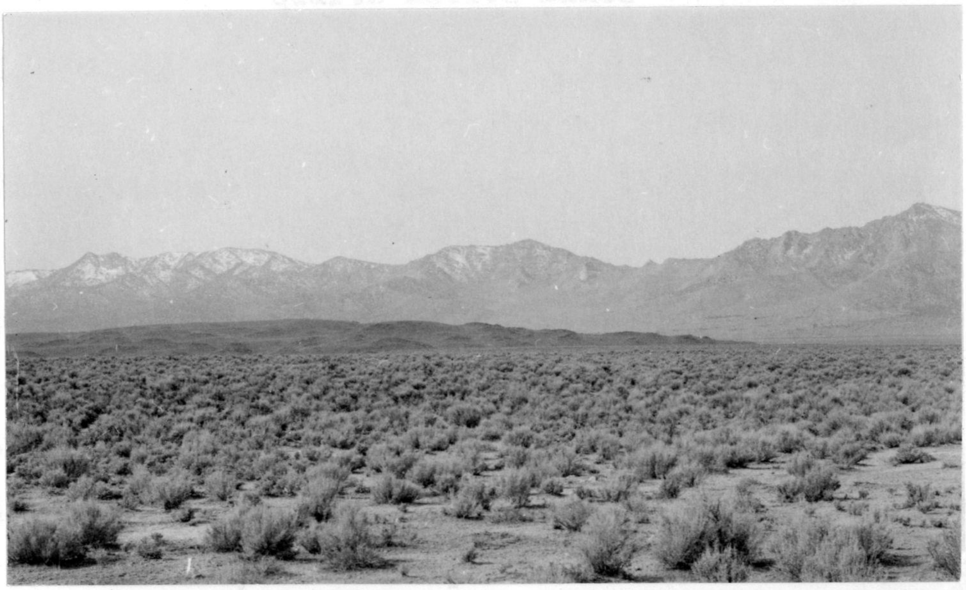

Plate 15.—Recent basalt flows near east side of the Mineral Range. View is southwestward. Flows can be traced to Cove Fort volcano, shown in Plate 14.

Age. The basaltic rocks are undoubtedly younger than the consolidated sediments exposed in the Northern Mineral Range. Less than a mile northwest of Lead Canyon, they unconformably overlie the lacustrine limestones of Tertiary or Quaternary age (See Plate 8, p. 33).

It is believed that the basalt is Recent in age, and is associated with the basic flows which are present in the south central part of Utah. The two basalt exposures on the eastern border of the Range are similar to those proximate to and associated with the Cove Fort volcano, and may be the same age and have the same ultimate source.

Hypabyssal Rocks

Quartz Latite Dikes

Field and petrographic description. A remarkable series of porphyritic quartz latite dikes is located within the eastern half of the Northern Mineral Range where it intrudes the granite and granodiorite. The dikes strike in general south southeast-north northwest, with comparatively minor irregularities. They have been observed to extend from the vicinity of the two rhyolite porphyry volcanoes on the south to the well defined igneous-sedimentary contact on the north, a distance of about 5 miles.

The continuity of the exposures of the dikes is interrupted chiefly by results of erosion and probable faulting, but partly by a cover of rhyolite float proximate to the volcanoes. Thicknesses of the dikes vary from 25 to about 200 feet, the thickest being exposed immediatly north of Pinnacle Pass. Most of the dikes dip to the west at angles which range from 5° to 60°. However, many are vertical and a few even are horizontal (See Plate 16).

The dikes weather to ledges, and are generally more resistant than the plutonic rocks they invade. This feature facilitates their observation from a distance (See Plate 17). Everywhere the dikes are heavily fractured, and weather to a reddish brown in places. The dikes are in sharp contact with the granite and granodiorite, and are of similar megascopic and microscopic appearance in both of these plutonic rocks.

Hand specimen examination reveals a rock which is distinctly porphyritic, with phenocrysts of quartz and feldspar in a fine grained matrix. Minor amounts of black crystals are conspicuous, but their presence does not detract from the predominant light gray color of the rock.

Under the microscope the quartz latite is seen to be of holocrystalline texture. The phenocrysts are quartz, orthoclase, and oligoclase, and range in size from .5 mm. to 1 mm. in diameter. The groundmass is a mosaic of quartz, feldspar, biotite, and magnetite which range in size from .1 mm. to .3 mm. in diameter (See Fig. 8).

More than 50% of the rock is composed of quartz, and the essential mineral orthoclase is subordinate to the oligoclase. Biotite and magnetite form the chief accessory minerals, and some apatite is undoubtedly present. The phenocrysts are anhedral to subhedral, and the mafic constituents are in general euhedral.

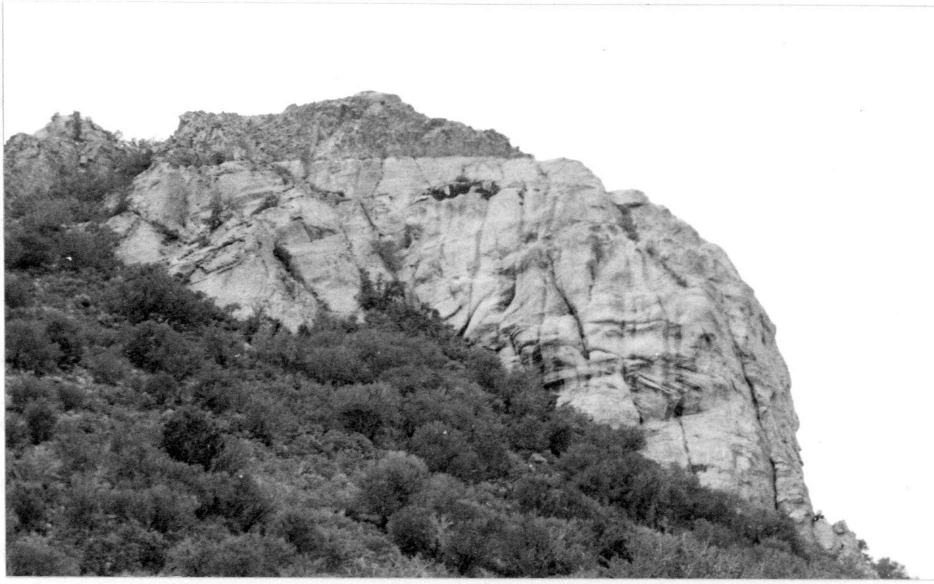

Plate 16.—View of part of a quartz latite dike cutting a granite exposure. Note sharp contact.

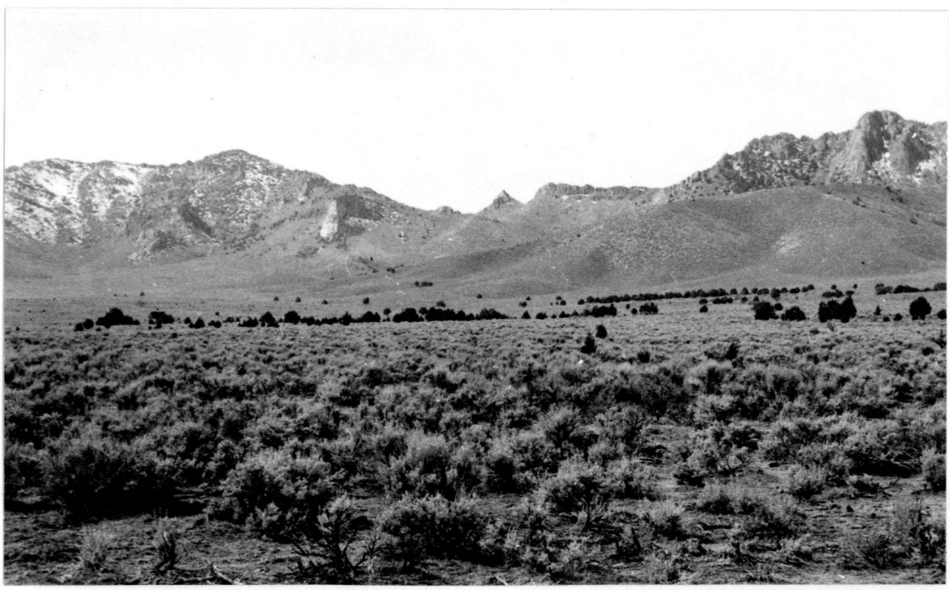

Plate 17.—View, looking westward, at Pinnacle Pass. Photograph shows numerous quartz latite dikes in the granite. The dikes are especially conspicuous at the left edge of the photograph, where snow is seen.

Age and origin. The quartz latite dikes intrude, and are younger than, both the granite and granodiorite. However, the dikes were not observed to invade the sedimentary rocks in the northern third of the area mapped.

The chemical and mineralogical similarity between the quartz latite dikes and the rhyolite porphyry volcanics suggest that they were derived from a common magmatic source. It seems probable that the dikes represent a late stage of fractionation during crystallization of the magma, and the rhyolite porphyry volcanics represent the final stages of activity.

There is other evidence which supports a magmatic, rather than a replacement origin for the quartz latite dikes. These are: (1) porphyritic texture; (2) sharp contacts with the granite and granodiorite; and (3) the dikes have matched borders.

Lamprophyre Dike

Field and petrographic description. The best exposure of the lamprophyre dike is located at the quartzite-limestone thrust contact, near the crest of the Range on the west side of the divide. Specifically, this and other exposures found by the writer were all located at the quartzite-limestone contact in the eastern half of Section 26, T. 25 S., R. 10 W.

The lamprophyre is apparently horizontal, and as the underlying and overlying sedimentary rocks, has been subjected to normal faulting transverse to the north-northwest trend of the Northern Mineral Range. In addition, quartzite talus covers much of the thrust plane. Therefore, the best and thickest exposure is about 12 feet in height, and can only be traced continuously for about 20 feet (See Plates 18 and 19).

Although the lamprophyre is generally concordant with the major structure, and probably has greater lateral extent as compared with the thickness, it is referred to as a dike since it has not invaded layers of sediment themselves but instead a thrust plane.

Megascopic examination reveals a dark greenish rock of medium, equigranular texture. The ferromagnesium constituents are in predominance over the lighter colored feldspars.

The study of two thin sections shows that about 50% of the lamprophyre is made up of euhedral and subhedral laths of sodic plagioclase, probably albite. There are abundant crystals of green hornblende, a smaller amount of biotite, and a little augite. The above constitute the essential minerals of the rock. Iron ore, sphene, olivine, and needles of apatite are the chief accessory minerals. Chlorite and sericite are the main secondary alteration products.

The texture is distinctly panidiomorphic, and the mafic minerals possess the best crystal outlines. The crystals range in size from less than .3 mm. to greater than .5 mm. in diameter (See Fig. 9).

<u>Significance of the lamprophyre</u>. The presence of the lamprophyre dike at the quartzite-limestone contact is significant because: (1) the lamprophyre may represent further evidence in support of the thrust fault concept in the Northern Mineral Range, as it probably represents intrusion along a plane of weakness; and (2) the position of the lamprophyre illustrates post-thrusting igneous activity.

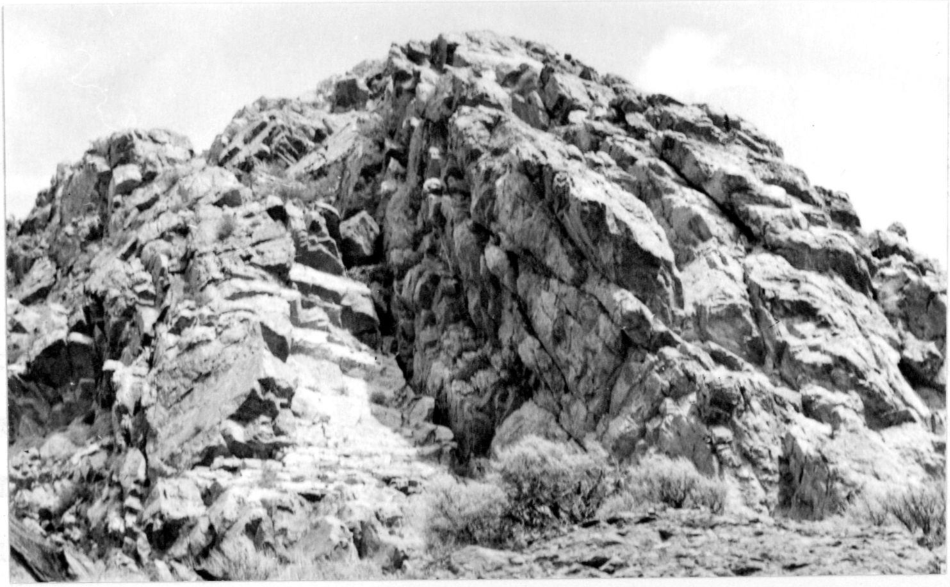

Plate 18.—Lamprophyre dike (bottom right foreground) shown in relation to Prospect Mountain quartzite. View is eastward, near crest of Range.

Plate 19.—Same exposure of lamprophyre as that shown in plate 18, but here view is northward and closer. Rectangular quartzite block (immediately above center) is one foot in length. Approximate contact between lamprophyre and Prospect Mountain quartzite shown by dashed line.

Other Hypabyssal Rocks

Field and petrographic description. Numerous basic, aplitic, and pegmatitic dikes are present in the Northern Mineral Range, and are generally confined to the area of plutonic exposures. Owing to the large number and small size of these dike bodies, they have not been noted on the geologic map. All of the dikes observed range in thickness from several inches up to 10 feet.

The minerals revealed under petrographic examination are:

(1) aplite-mainly quartz and orthoclase, with accessory amounts of plagioclase, biotite, and magnetite.

(2) andesitic and/or lamprophyric dikes-plagioclase predominant over orthoclase, and the chief mafics are horblende and biotite; sericite and chlorite present, with minor quartz.

All of the pegmatites observed in the Northern Mineral Range were found to be of simple mineralogy, but Earll has noted the presence of beryl, topaz. tourmaline, and apatite within some of the pegmatites in the Central Mineral Range.

Age and origin. The pegmatites associated with the granitic and granodioritic magmatic bodies are probably of late stage crystallization in the magmatic cycle, but it is much more difficult to reconstruct differentiation of basic and aplitic dikes. According to Turner and Verhoogen (1951), textbook concepts involve vaguely understood mechanisms of differentiation in opposite directions, with granitic magma as the common parent. Moreover, it appears exceptionally difficult to reconstruct basic differentiates from granitic magma in terms of experimentally determined data of silicate crystallization. The problem, in short, is not

solved.

Since the dikes pervade the plutonic rocks, they must be considered to be younger in age. Nowhere were the dikes found together, and so it was not possible to determine ages relative to each other.

METAMORPHIC ZONES

Three distinct metamorphic zones have been depicted on the geologic map. The zones have been classified as: (1) marble-hornfels zone; (2) tremolitized zones; and (3) basic zone. Numerous other areas of metamorphism are present in the sedimentary division, and are associated with fault zones. Owing to their small size, they have not been noted on the map.

Marble-Hornfels Zone

Field and petrographic description. The marble-hornfels zone borders the granodiorite body on the north and is easily distinguishable at a distance from the range (See Plate 20). The aureole is comprised of Middle Cambrian Pioche shale and overlying undifferentiated Cambrian limestone. The rocks have been metamorphosed to hornfelsic argillite and marble for the most part, but alteration has been irregular since many patches of only slightly metamorphosed, and even fresh rock, are present. Measured normal to the granodiorite, the contact zone is approximately 2,200 feet in width. Adjacent to the aureole, quartzite is exposed, but does not exhibit any noticeable metamorphic effects

Microscopic examination of the argillite reveals crystals of andalusite(?) embedded in a fine grained matrix of quartz and clay minerals. Sericite is present in minor amounts, as is chlorite and inclusions of carbonaceous matter.

Plate 20.—View, looking westward, which shows marble-hornfels zone in contact with granodiorite to the south. Contact noted by dashed line. Basalt outcrop in foreground, at base of Range.

Petrographic analysis of the metamorphosed limestone reveals crystals of phlogopite and quartz in sections composed mainly of a mosaic of equant grains of calcite. The quartz and phlogopite are minor in amount, but vary in proportion to the degree of alteration of the limestone.

Source and type of metamorphism. The Cambrian sediments have been subjected, probably, to high temperature contact metamorphism. The close association of the aureole with the igneous intrusion indicates that recrystallization was directly caused by the latter. In no place were garnet-rich zones present, and in the 4 thin sections examined the silicate minerals are subordinate and have not greatly affected the original mineral assemblage. The irregular additions from the intrusive, and apparent selective metamorphism is not clearly explainable. It may be due to: (1) the attitude of the strata with respect to the intrusion (strata dip toward intrusion); (2) the overall fault pattern and development of channels; (3) pre-alteration composition or textural variations of the sedimentary rocks; and/or (4) character and compositional variations of the magma.

Tremolitized Zones

Field and petrographic description. On both the west and east sides of the Northern Mineral Range, about $1\frac{1}{4}$ to $1\frac{1}{2}$ miles north of the exposed granodiorite, are two well defined tremolitized limestone zones. The zones are generally equidimensional and are located at approximately the same latitude.

The color of the tremolitized rock is dark gray with minor patches of white. In general, the mineral occurs in randomly oriented fibrous aggregates. Metamorphism varies in intensity, and numerous local areas of finely crystalline, fresh limestone are found within the zones. Megascopically, the rock contains more than 50% tremolite where the mineral is most abundant.

Microscopic examination reveals carbonate (calcite and dolomite), tremolite, and minor quartz and mica. The proportions of carbonate and tremolite vary considerably with different thin sections, but the quartz and mica remain constantly below 10% in volume. In specimens where tremolite is minor, it occurs as long prismatic crystals rather than fibrous aggregates.

Source and type of metamorphism. The formation of tremolite in the Northern Mineral Range is probably the result of contact metamorphism of dolomitic limestones. The source of the components necessary for tremolitization was probably an intrusive body, which could be buried at shallow depths beneath the contact zones.

The presence of a subjacent intrusive is further suggested by the presence of a small outcrop of a cordierite-bearing rock, found within the tremolitized zone on the west side of the Range. Accessory minerals are rutile, sericite, and tourmaline. According to Rogers and Kerr (1942), cordierite is a typical metamorphic mineral, often found at the contact with persilic igneous rocks.

Basic Zone

Information accumulated from field investigation and limited petrographic analysis suggests the presence of granitization, at least as a restricted process operating along the western margin of the Northern and Central Mineral Range.

Field description. The basic zone is located along the western margin of the granitic mass of the Northern Mineral Range, and is traceable southward into the Central Mineral Range for an additional distance of almost 5 miles (Earll). The exposures in the Northern Mineral Range vary in size and shape. In general, however, individual outcrops are linear and exceed 1,000 feet in length and 200 feet in width. The trend of the basic zone, when considered as one unit, is generally parallel to the north-northwest axis of the Range. The exposures are restricted to slopes and saddles for the most part.

The zone is comprised predominantly of dark, basic, ferromagnesium-rich constituents, and from a distance appears to be in sharp contact with the lighter colored granite (See Plate 21). However, upon closer examination of several outcrops, a distinct but narrow (up to 50 feet) transitional zone was found to exist. This zone contains abundant inclusions which in places are distinctly oriented (See Plate 22).

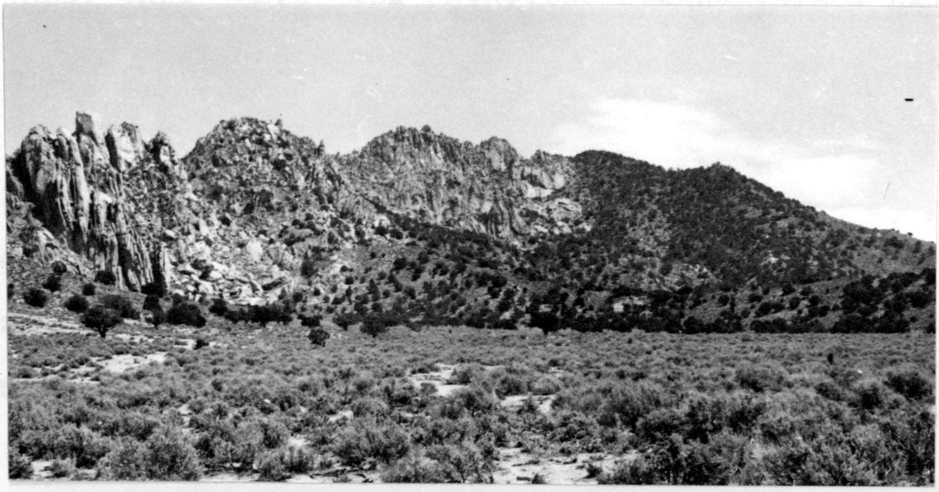

Plate 21.-Basic zone in contact with granite. View is eastward.

Plate 22.- Local zone of oriented inclusions transitional between the basic zone and the granite. Handle of pick shows general trend of orientation.

Although the main part of the zone consists of a medium to coarse grained equigranular rock of dioritic composition, there is both compositional and textural variation in the narrow transitional zone. Here, the "diorite" grades into a "porphyritic" (porphyroblastic) rock containing metacrysts of feldspar and a fine to medium grained groundmass similar in composition to the normal coarse granite. The metacrysts approximate the size and shape of the crystals of the granite, and upon hand specimen examination of the two rocks a metasomatic process of development seems possible (See Plate 23).

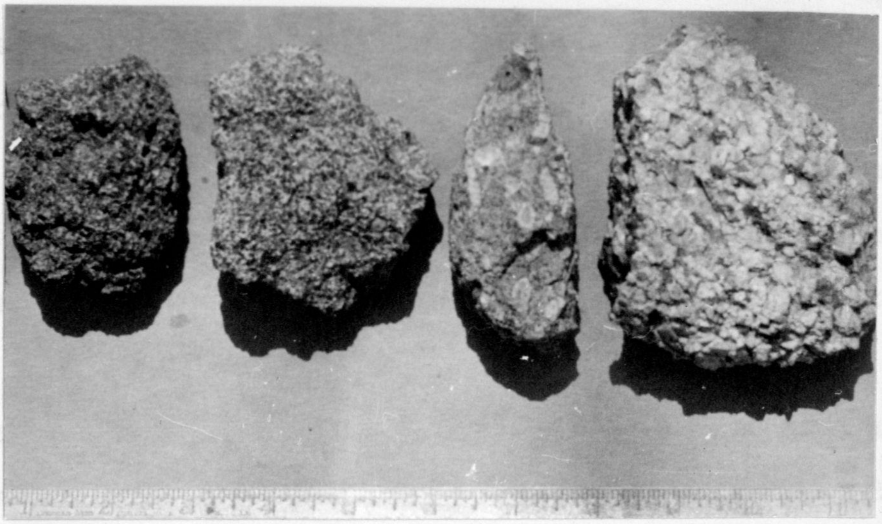

Plate 23.- Hand specimens of basic and narrow transitional zone, and granite. Photograph shows transition from "dioritic" rock on left, through porphyroblastic specimen, and finally into coarse grained granite.

In the Central Mineral Range an outer gneissic zone exists, and Earll has informed the writer that the basic zone grades into this gneissic zone. Earll believes they may be Precambrian metasediments and that the basic exposures possibly represent a more reconstituted facies developed from the gneissic rock.

<u>Petrographic description</u>. Six samples were collected for microscopic study from one of the northernmost basic exposures, located in Section 10, T. 26 S., R. 10 W. Selection of samples was based on variations in composition and texture as observed in the field.

Microscopic study of the specimens collected shows that rocks of dioritic, granodioritic, and quartz monzonitic composition are present. There follows below a brief description of each of these rock types.

(1) "Diorite": comprises most of basic zone; biotite and hornblende (20% to 40%) and andesine (10% to 20%) are most abundant minerals; quartz and potash feldspar each make up less than 10% of rock; sphene unusually abundant (more than 5%); sericite and chlorite common; magnetite chief accessory mineral. Texture is typically granoblastic; crystals range from .3 mm. to more than .5 mm. in diameter; biotite, hornblende, sphene, and andesine crystals are subhedral to euhedral; interstitial quartz anhedra; magnetite is euhedral and anhedral.

(2) "Granodiorite": represents nonporphyroblastic inclusion in coarse granite in narrow transitional zone; andesine (20% to 30%) most abundant mineral; quartz and potash feldspar have increased (10% to 15%); biotite (less than 15%) and a little or no hornblende; chlorite and sericite chief alteration products; microcline, sphene, and magnetite most common accessory minerals; some apatite crystals. Texture is granoblastic, although megascopic appearance suggests definite orientation of crystals; average crystal size less than .5 mm. in diameter; most grains subhedral to anhedral; microperthitic structures are suggested,

but not well developed.

(3) "Quartz monzonite": also from the transitional zone, as was #2; quartz (up to 35%) predominant mineral; orthoclase and microcline together approximately equal oligoclase in volume; biotite (10% to 15%) chief mafic mineral; chlorite and sericite still common alteration products; magnetite, hornblende, sphene and apatite chief accessory minerals. Texture is porphyroblastic; metacrysts are feldspars; groundmass is chiefly subhedral and anhedral grains of quartz, feldspar, and biotite, which range from .1 mm. to .4 mm. in diameter. Microperthitic structures involving sodic plagioclase and microcline are present.

Mode of development. Speculation concerning the manner of development of the basic zone in the Mineral Range is limited to three possible choices. They are: (1) assimilation of the original rock by a granitic magma; (2) granitization of the original rock in place, with the components necessary for transformation being supplied by the granitic intrusion; and (3) a combination of the two processes.

It is conservatively believed that the zone has been developed through a combination of the two processes mentioned above. More conclusive evidence for the existence and predominance of each of these processes, and the scale to which they have been affective, may only be possible through more detailed field mapping and extensive laboratory examination. However, the evidence accumulated which suggests the presence of granitization, at least as a restricted process operating along the western margin of the Mineral Range, are: (1) local orientation of inclusions; (2) presence of metacrysts of feldspar similar to those

which partly comprise the normal coarse granite; (3) narrow, but gradational contacts between the granite and the basic zone; (4) presence of microperthitic structures and possibly others associated with replacement.

STRUCTURE

General Considerations

The structural features which characterize the Northern Mineral Range are in general similar in nature to those of other ranges within the Basin and Range Province. Therefore, prior to any discussion concerning the structure of the area mapped, a bief review of the structural history of the Province is given. Nolan (1943, p. 142) has summarized this as follows:

> "The geosynclinal sea which in the early part of the Paleozoic era covered most of the province and in which many thousands of feet of sediments were deposited was divided in late Devonian time by a rising arch or geanticline in western Nevada. Locally there was moderate deformation during the uplift, but by Permian time elevation had ceased and most of the positive area had been covered by marine sediments. Coincidentally with the degradation of this geanticline during the Permian epoch similar uplift began in eastern Nevada, and a land mass between two seas persisted there, until early Jurassic time, when, instead of subsiding as the earlier one did, it became the site of intense diastrophism, marked particularly by large overthrust faults. To judge from the relatively meager evidence available, recurrent epochs of similar deformation continued into early Tertiary time, affecting an area that considerably exceeded that of the Basin and Range province..... The Mesozoic and early Tertiary folding and overthrusting were succeeded closely by the initiation of the block faulting that has been the chief cause, directly or indirectly, of the present relief of the province. The faulting appears to have started at least by early Oligocene and to have continued up to the present day."

Hintze, (1951, p. 25) states:

> "The block faulting has served to afford fine exposures of the Paleozoic column in various ranges throughout the province.... Thrust faulting, however, may have served to dislocate the sections from their original depositional site. Structural studies of the Great Basin have not proceeded far enough to determine the amount of the dis-

> placement or even the locus of the thrust plates except in a few instances. In central Nevada, Merriam and Anderson (1942) have postulated a thrust which has brought the western shaly facies (Vinini) of the Ordovician into juxtaposition with the Pogonip limestone facies. Thrust faulting is known in several localities in south central Nevada, and there appears to be a belt of thrusts in a line slightly east of north through central Nevada. Longwell (1949) and Hewett (1931) in their studies of the Muddy Mountains and Goodsprings areas of southern Nevada show extensive thrusting, and other thrusts have been found in a belt connecting the southern Nevada region with the thrusts in the Wasatch Mountains near Ogden, Utah (Eardley, 1944). Intermediate areas in this belt where thrusting is recognized are Pioche, Nevada (Westgate and Knopf, 1932), San Francisco, Utah (Hintze, 1949), Pavant Range, Utah (Maxey, 1946), Canyon Range, Utah (Christiansen, 1950), Gold Hill, Utah (Nolan, 1935), Sheeprock Range, Utah (Loughlin in Butler, 1920), Southern Wasatch Range, Utah (Eardley, 1934), and Oquirrh Range, Utah (Gilluly, 1932)."

The Mineral Range, with respect to the regional structure, is located in the belt of thrusting which connects the southern Nevada region with the thrusts in the Wasatch Mountains. Specifically, it is situated about 20 miles east of the San Francisco Mountains; about 50 miles southwest of the Canyon Range; and about 35 miles southwest of the Pavant Range (See Fig. 2).

Structures in the Northern Mineral Range

Folds

The sedimentary division of the Northern Mineral Range has been gently folded or domed, with the beds on the south dipping in general to the south, and those on the north dipping in general to the north. Periods of normal faulting, subsequent to the formation of the folds, have in part masked or destroyed the original dome-like structure.

The only areas where closed local folds are abundant are within the zones of tremolitization, which are depicted on the geologic map and sections.

No conclusive field evidence has been discovered which can show with certainty the cause of the doming of the sediments in the Northern Mineral Range. However, it is believed by the writer that the folds may be directly related to an intrusion of an igneous body which may lie beneath the central part of the sedimentary division. There are three field evidences which have led the writer to this opinion. They are: (1) the presence of two tremolitized zones, essentially equidimensional and located at about the same latitudes, exposed at the surface on the west and east sides of the Range; (2) the presence of a lamprophyric body at the quartzite-limestone thrust contact, located within the latitudinal boundaries of the tremolitized zones and not observed in any other area of the sedimentary division; and (3) the sedimentary division has undergone normal faulting transverse to the trend of the Range, and the downfaulted blocks in the northern part dip to the north and those in the southern part dip to the south. The above noted nonconclusive evidences have been described in detail in their appropriate sections of this report, and the reader is referred to them for further or additional data.

Of interest, perhaps, is the fact that Butler (1913, p. 70) has described distinct doming of the sedimentary rocks by a quartz monzonite intrusive in the Cactus area of the San Francisco Mountains located 20 miles to the west, as well as inferring that similar relationships exist in adjacent areas.

The writer acknowledges the fact that the normal faults could have been due to vertical forces not related to igneous activity, and that the presence and geographic position of the tremolitized zones and the lamprophyric body are purely coincidental and may be related to an intrusive located at almost any distance from these critical areas. However, a subjacent igneous body could account for: (1) doming of the sedimentary division; (2) normal transverse faulting; (3) igneous activity distinct from the main granitic episode; and (4) more than one stage of metamorphism and mineralization. Therefore, the writer is inclined to believe that a subsurface igneous body could, and probably does, exist below the central part of the domed section of the Range.

Faults

The most prominent structural features of the Northern Mineral Range are normal faults and one major thrust fault. The normal faults, for the purpose of discussion, are divided into two types: (1) faults transverse to the trend of the Range; and (2) longitudinal and border faults.

The existence of faults can be determined, based chiefly on: (1) displacement of specific lithologic units; (2) abnormal stratigraphic sequences (older on younger rocks); and (3) existence of fault-line scarps, fault planes, zones of brecciation and slickensided fragments. However, the nature of origin and chronologic development of the faults in the Northern Mineral Range can only be postulated due to the fact that no field evidence was discovered that is sufficient for precise determination.

Therefore, it has been necessary to correlate, in general, the tectonic history of the Northern Mineral Range with that of adjacent areas and the Basin and Range Province in which it is located.

Northern Mineral Range Thrust

The writer discovered evidence which shows that the conformable Prospect Mountain quartzite-Pioche shale-Undifferentiated limestone sequence, of Cambrian age, which is present in the northern third of the Northern Mineral Range, is probably part of an overthrust plate.

No identifiable fossils or fossil fragments were found in the limestones underlying the thrust plate, and therefore these rocks were not definitely proven to be younger. In addition, no mylonite zone nor zone of brecciation was found at the contact, where it is exposed. Quartzite talus covers most of the contact zone, and consequently close examination of the thrust plane was difficult. Subsequent normal faulting and intervals of erosion have in part destroyed the continuity of the original thrust plate, thus making the solution of the problem more difficult. The following is a list and brief description of specific evidences which favor the existence of a thrust plate in the Northern Mineral Range.

Stratigraphic evidence. The essentially conclusive evidence in favor of an overthrust is the fact that the quartzite-shale-limestone sequence is older than the underlying limestones. (Refer to geologic map and sections). The evidence for this relationship follows:

(1) The quartzite is conformably overlain by the Pioche shale, which contains Middle Cambrian fossil fragments near the north end of the Range, and is therefore considered to be late Lower to Middle Cambrian in age. Moreover, the lithologic character and sequence (quartzite-shale-limestone) is consistent throughout the northern third of the area mapped, and is similar to the tripartite lithologic divisions of Cambrian rock in the Rocky Mountain area. Therefore, the above mentioned rock units have been referred to in this report as Prospect Mountain quartzite; Pioche shale; and Undifferentiated limestone. The reader is referred to the section on stratigraphy for description of these units.

(2) The limestone underlying the thrust plate has been correlated specifically with the undifferentiated Middle(?) and Upper Cambrian carbonate rocks in the San Francisco Mountains, mainly on the basis of lithologic identity and similar metamorphic effects. In addition, the limestones underlying the thrust plate are similar to the Middle or Upper Cambrian limestones located in the hills just north of Black Rock (See Fig. 2), as well as those exposed in the Great Basin region in general. Therefore, on a regional basis, the limestones underlying the thrust plate in the Northern Mineral Range are tentatively classified as Middle or Upper Cambrian(?). The reader is referred to the section on stratigraphy for a detailed description of these limestones.

The most similar normal limestone-quartzite sequence which is exposed in parts of Utah and Nevada, and which upon cursory examination was initially believed to exist in the Northern Mineral Range, is the Ordovician Pogonip-Swan Peak and Eureka sequence. The evidence indicating that the sequence is not Ordovician in age is listed and briefly described below:

(1) In most localities where the Ordovician sequence is known, the Pogonip carbonates and shales grade into the overlying Swan Peak and/or Eureka quartzites, and fossils are abundant in the upper members of the Pogonip Group. This type of contact is not present in the Northern Mineral Range, as the underlying uniform limestone (not a single shale unit was found in the 1,200 foot measured section) was observed to be unfossiliferous and is in comparatively sharp contact, except locally where an igneous dike is present, with the overlying quartzite.

(2) In most areas of Utah and Nevada, where the Swan Peak and Eureka quartzites are present, they are immediately overlain by dolomite. The thin shale unit which conformably overlies the quartzite in the Northern Mineral Range, in addition to containing Middle Cambrian fossils, does not correlate lithologically with the Ordovician sequence. The reader is referred to the publication by L.F. Hintze (1951) for a detailed description of part of the Ordovician stratigraphy in western Utah, and also the paper by H. Schneider (1949) for a summary of the Cambrian stratigraphy of Utah.

<u>Structural evidence</u>. There are two evidences which suggest that a thrust relationship exists between the overlying quartzite-shale-limestone sequence and the underlying limestone of uniform lithology. The first is found within the Northern Mineral Range, and the second is based on correlation with structural features in adjacent areas.

(1) A tabular lamprophyric body exists locally at the contact between the two sedimentary units in question, although quartzite talus has covered most of the critical area (See Fig. 1 and Plates 18 and 19). The development of an igneous intrusion in this area, and in this area only with respect to the sedimentary rocks, suggests that a plane or zone of weakness exists between the limestone and quartzite units, which is considered to be the thrust plane. Description of this igneous body is presented under the section on hypabyssal rocks.

(2) The overthrusting of Cambrian rocks in the Northern Mineral Range is in harmony with the proven overthrusts in adjacent areas, such as the Canyon and Pavant Ranges and the San Francisco Mountains (See Fig. 2). A brief description of the thrusting in these areas is presented in the subdivision concerning the age of thrusting. There are indications of thrusting in the Central Mineral Range, but at the present time no definite conclusions, concerning that area, have been reached by Earll (personal communication).

Other considerations. There are some structural features, and the absence of others, that have raised some questions as to the validity of the thrust fault concept in the Northern Mineral Range. They are:

(1) The fact that no mylonite nor breccia zone was found to exist at the quartzite-limestone contact may be taken for evidence which disfavors overthrusting in the Northern Mineral Range. The writer acknowledges this, but does not mean to infer that no brecciated areas are present in the vicinity of the con-

tact. There are several, one of these being shown in plates 24 and 25. However, it is believed that these zones are related to normal faulting which has displaced the thrust plate in several places, and are not related to the overthrusting.

(2) The fact that there is no observable marked disparity in attitude between the quartzite and underlying limestones (See Plate 26 and Fig. 1) might raise another question about the validity of the overthrust concept, but this structural relationship is not uncommon in areas of known overthrusting.

Age of thrusting. From direct field evidence within the area mapped, it can only be shown that thrusting in the Northern Mineral Range occurred between Cambrian(?) and probably Cretaceous(?) time.

Owing to the fact that carbonate rocks of questionable Cambrian age are the youngest units involved in the thrusting, it can be definitely stated that the thrusting postdates the carbonate rocks underlying the thrust sheet, and probably predates the Indianola(?) conglomerate of Cretaceous(?) age, which unconformably overlies the Cambrian sequence near the north end of the Range.

In order to postulate a more narrow range for the age of thrusting, it was necessary to refer to adjacent areas which have been subjected to thrusting, and which involve, in part, similarly dated rocks. The location of these areas, specifically the Canyon and Pavant Ranges and the San Francisco Mountains, are shown on the index map, figure 2.

Two episodes of thrusting in the Canyon Range have been recorded by Christiansen (1950). The first phase began in Late

Plate 24.—Brecciated zone along normal fault in vicinity of thrust plane, near crest of Range. Note geology pick immediately above center.

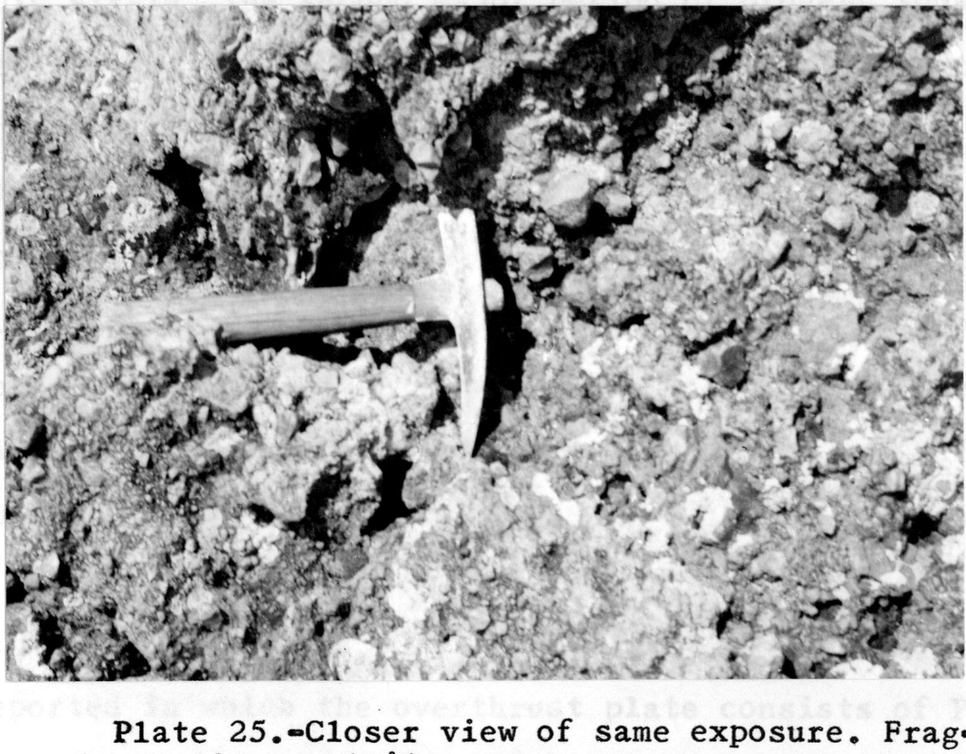

Plate 25.—Closer view of same exposure. Fragments mostly quartzite.

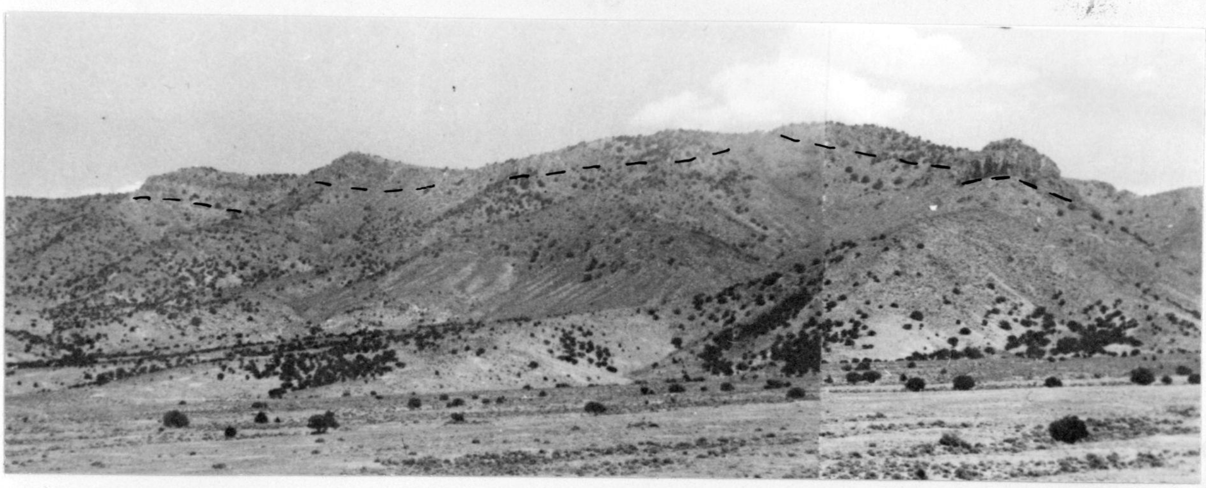

Plate 26.—View, looking eastward, which shows quartzite forming crest of the Range and underlying Cambrian(?) limestone. Dashed line marks approximate contact. Quartzite exposure near right edge of photograph is an isolated remnant or "klippe" from the main thrust plate. Tremolitized limestone zone near base of Range, left of center.

Jurassic(?) and culminated in the Early Cretaceous. This thrusting involved Precambrian rocks which were thrust over Early Paleozoic strata. The second major period of orogeny took place in Early Laramide time, in which Precambrian rocks were thrust over Indianola(?) conglomerates.

In the Pavant Range (Maxey, 1946), a thrust plate, composed of Lower Cambrian quartzite, Middle Cambrian shales and limestones, and Upper Cambrian(?) limestones, overthrusted Permian rocks and sandstones of Triassic and Jurassic age. The thrust plate, in turn, is unconformably overlain by the Tertiary Wasatch formation. Therefore, according to Maxey, the time of major thrusting in the Pavant Range is post-Jurassic and pre-Eocene(?).

In the San Francisco Mountains (East, 1957), thrusting has been reported in which the overthrust plate consists of Precambrian and Lower Cambrian Prospect Mountain quartzite, and overrides carbonate rocks of Cambrian, Cambrian(?), and Ordovician age. Locally, rhyolite tuff-breccia lies unconformably on the eroded surface of the quartzite thrust plate, and these volcanic rocks are probably Late Oligocene in age, according to East. Therefore, the thrusting in the San Francisco Mountains can be dated as post-Ordovician and probably pre-Oligocene. However, East correlates the thrusting with the earlier thrusting in the Canyon Range, and concludes that the main movement is late Mesozoic and pre-Laramide in age.

In view of the above, the writer believes that the Northern Mineral Range thrust probably took place prior to the Laramide Orogeny, and represents a part of the thrust belt developed during Late Jurassic(?) and Early Cretaceous time.

Normal Faults

Field evidence, such as: (1)displacement of specific rock units; (2)presence of actual fault planes; (3)fault-line scarps; and (4)local areas of metamorphism, mineralization, brecciation and slickensided fragments---reveal the presence of numerous normal faults. These faults consist of a transverse system which generally strikes east-west, and a longitudinal system which is roughly parallel to the north-northwest trend of the Range. All of the faults observed are believed to postdate the thrusting, but this does not preclude the possibility that earlier period(s) of normal faulting did occur.

Transverse faults. The most prominent normal faults which transverse the Range occur near the north and south ends of the sedimentary division (See Fig. 1). At these localities, the strata have been normally faulted owing to essentially vertical stresses which were possibly caused by subsurface intrusive activity and doming of the central sedimentary part of the Northern Mineral Range.

The faults at the north end dip 45° to 65° to the north, and the downthrown blocks on the north are comprised of a part of the normal Cambrian quartzite-shale-limestone sequence and the overlying Indianola(?) conglomerate. The base of the quartzite is not exposed in this area, and thus the net slip was not possible to be determined, but it is a minimum of 500 feet.

Near the south end of the thrust plate, the metamorphosed Cambrian shales and limestones have been normally faulted, the downthrown block being to the south. The faults dip 60° to 70° to the south (See Fig. 1, section A-A'), and determination of the net slip was not possible.

Remnants of quartzite are found on the western margin of the sedimentary division, considerably remote from the main thrust plate (See Fig. 1 and Plate 27). The central part moved upward with respect to the marginal blocks, but it is not known whether the forces were caused by intrusion(?) and doming, or if it is associated with a later(?) period of Basin and Range faulting.

Several other normal faults displace the thrust plate. Their presence, in addition to the above noted displacement, is evidenced by local areas of alteration, exposure of fault planes, and zones of brecciation and slickensided fragments.

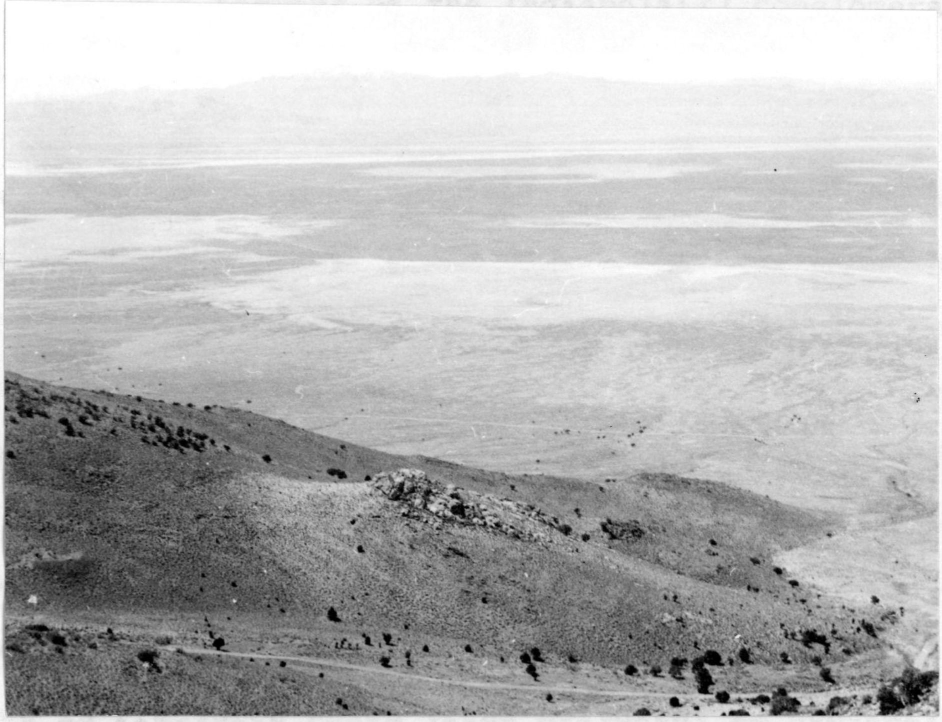

Plate 27.-Isolated quartzite remnant on northwest side of Range, adjacent to Lead Canyon. View is southwestward. San Francisco Mountains form part of background.

Longitudinal and border faults. Many of the topographic features which characterize the Northern Mineral Range are the direct result of normal longitudinal faulting. The general trends and type of faulting are similar to the Basin and Range faults which are common in the Great Basin Province, and which were initiated in Middle Tertiary time. These faults have probably been intermittently active up to the present.

On the basis of field evidence it can be shown that the longitudinal faults are generally younger than the transverse faults. The dips of the normal longitudinal faults range from 50° to more than 70° toward the intermontane valleys.

Near the northeast end of the Range, a longitudinal fault has displaced a segment of the Indianola(?) conglomerate which had previously been disrupted by a major normal transverse fault. This longitudinal fault, as well as several others which exist in the interior of the Range, shows well defined fault-line scarps and is easily discernable at a distance from the Range.

The longitudinal faults form a zone of faults rather than a single long and continuous structure. They cannot be traced into the intrusive mass to the south, nor are they seen to abruptly terminate at the igneous-sedimentary contact. However, a longitudinal fault system within the igneous mass(es) is indicated by the series of quartz latite dikes which is located in fractures which trend northwest in general. Most of these dikes dip toward the west and southwest, and the fractures may be related in age to the longitudinal faulting which occurs farther north and involves the sedimentary rocks.

Evidence favoring the existence of a border fault on the east side of the Range may be summarized as follows: (1) the relatively steep and straight range front is suggestive of displacement on a large scale; and (2) the alignment and coincidence of small patches of young basaltic flows along the flank of the Range.

Evidence for the existence of a border fault on the west side has not been observed in the field. However, by referring to the geologic map and projecting the general strike of the quartz latite dikes, it does not seem unreasonable to suppose that a border fault could exist along part of the western side of the Northern Mineral Range.

Summary of Age of Faults

(1) Thrusting of the older Cambrian quartzite-shale-limestone sequence over younger Cambrian(?) limestones is the earliest phase of faulting observed in the Northern Mineral Range, and is tentatively dated as Late Jurassic(?) to Early Cretaceous.

(2) A series of normal transverse faults which cuts across the thrust plate and has involved the Cretaceous(?) conglomerate represents the next phase of faulting. These faults are post-Cretaceous(?), and in part at least, probably pre-Miocene, thus they may be related to the Laramide orogeny.

(3) The first part of the third and last stage of faulting is probably related to an early phase of Basin and Range movements, and is represented by the interior, longitudinal normal faults. The second part of the third stage of faulting is represented by the postulated border fault(s), related to later Basin and Range movements. The longitudinal and border faults have probably been intermittently active since Middle Tertiary time.

SUMMARY OF GEOLOGIC HISTORY

The sedimentary record is incompletely represented in the Northern Mineral Range. Therefore, any interpretative summary of a sequence of geologic events up to the present in certain instances necessitates reference to adjacent areas.

Precambrian(?). The only rocks in the Northern Mineral Range which may be of Precambrian age are represented by a basic zone located along the western margin of the granite. The zone is traceable into the Central Mineral Range where it has been observed to grade into gneissic rocks. Earll (personal communication) believes that the basic and gneissic rocks may be Precambrian in age, but has not completed his investigations of the critical area.

If these rocks are proven to be Precambrian, then it would tend to support the postulation by Butler (1920, p. 100) that a structural high or uplift extends east-west across the Tushar, Mineral, San Francisco, and Wah Wah Ranges (See Fig. 2), in which Precambrian rocks have been raised above the present erosion surface.

Paleozoic. The only sedimentary formations in the Northern Mineral Range which belong to the Paleozoic Era are the Prospect Mountain quartzite, Pioche shale, and Undifferentiated limestone of known Cambrian age, and limestones of questionable Cambrian age.

Although the known Cambrian sequence is probably allocthonous, it indicates deposition in a normal sea which transgressed from the southwest through Utah during Cambrian time.

In the Central Mineral Range, Earll reports exposures of Lower Paleozoic, Pennsylvanian(?), and Permian rocks. Therefore, since there is no evidence to the contrary, it seems probable that the Mineral Range was subjected to fairly constant subsidence and sedimentation during the Paleozoic, with intermittent periods of emergence and nondeposition.

Mesozoic and Cenozoic. No direct field evidence was found in the Northern Mineral Range, but it is probable that marine deposition continued into Late Triassic time, when epeirogenic uplift caused withdrawal of the sea and the Moenkopi formation was deposited, part of which is exposed in the Central Mineral Range (Earll).

Near the end of the Jurassic, crustal disturbances of major proportions commenced to develop, and it was between Late Jurassic(? and Early Cretaceous that the Northern Mineral Range thrusting is thought to have occurred.

Deposition of the Indianola(?) conglomerate, near the north end of the Range and overlying part of the thrust plate, represents a deposit perhaps related to Late Mesozoic or Early Tertiary orogeny.

Doming of the sedimentary division resulted in normal, transverse faulting, which could have been due to a subsurface igneous body. The transverse faults are probably related in time to the Laramide Orogeny. It also seems possible that metamorphism (dolomitization) developed during this period of igneous activity(?), doming, and transverse faulting.

Intrusion of the main granodioritic-granitic mass(es), which resulted in metamorphism of the Cambrian rocks adjacent to the granodiorite, to argillite and marble. Tremolitization was possibly effected at this time, which is thought to be Early(?) and/or Middle Tertiary.

Initiation of interior longitudinal normal faults, probably related to an early stage of Basin and Range faulting, in Middle Tertiary time.

More acidic igneous activity is represented by the series of quartz latite dikes developed along a fracture zone which is roughly paralell to the longitudinal faults present within the sedimentary division, and which may be related in time and origin.

A volcanic episode, represented by two rhyolite porphyry cones, is presumed to be Late(?) Tertiary in age.

Initiation of the Basin and Range eastern border fault, with movements during Pliocene(?). No scarplets or other evidences of Recent movement were discovered.

Deposits of lacustrine limestone on the valley floor, of questionable Quaternary age, may be related to older Tertiary deposits of similar origin.

Erosion, which was predominant after initial uplift of the Range, resulted in alluviation of the valley plain.

Lake Bonneville extended into the valley in Late Pleistocene time, depositing gravels, sands, and clays, and which is evidenced by the presence of spits and bars a short distance from the western side of the Range.

Extrusion of Recent basalt along the postulated eastern border fault, and in the valley plain to the east and north of the Range.

Continued erosion and alluviation, the deposits being chiefly derived from the Range and deposited in the valleys. Alluvial fans were built up along the flanks of the area.

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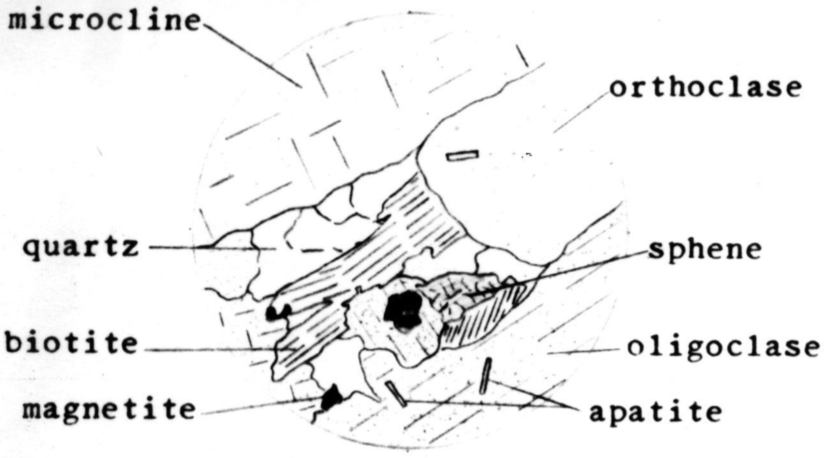
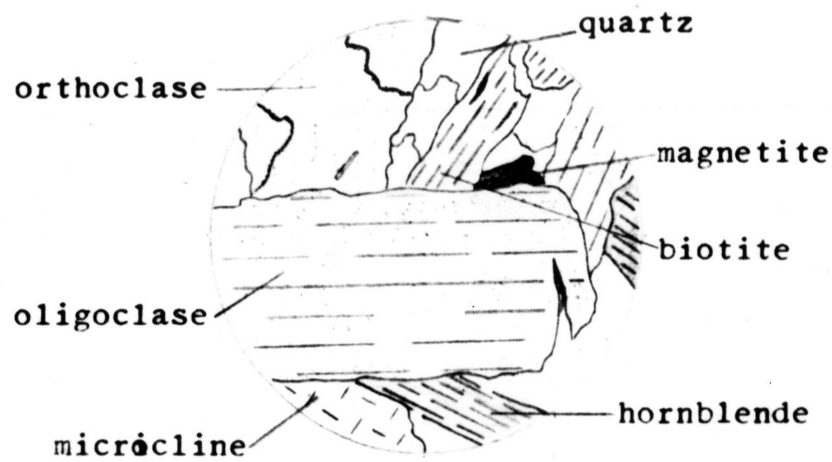


GRANITE

Figure 4.

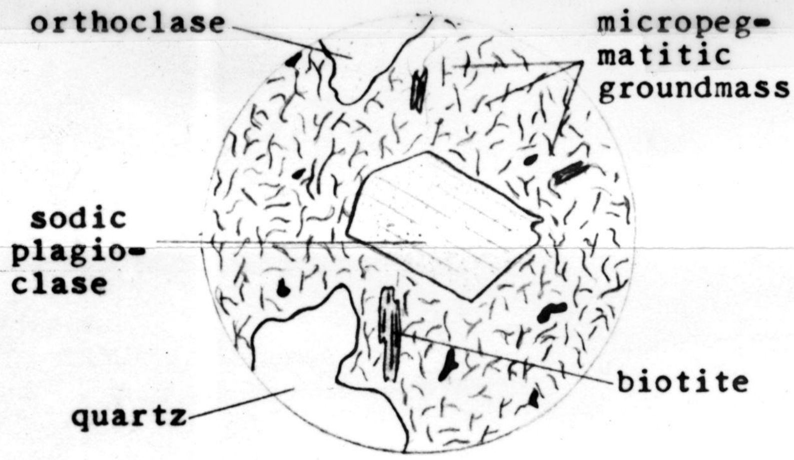
Diam. 2 mm. Composed mainly of microcline and orthoclase, oligoclase, quartz, and biotite. Accessory magnetite, etc.



GRANODIORITE

Figure 5.

Diam. 2mm. Oligoclase (30%); also microcline, orthoclase, quartz, hornblende, & biotite. Same accessories as #4.



RHYOLITE PORPHYRY

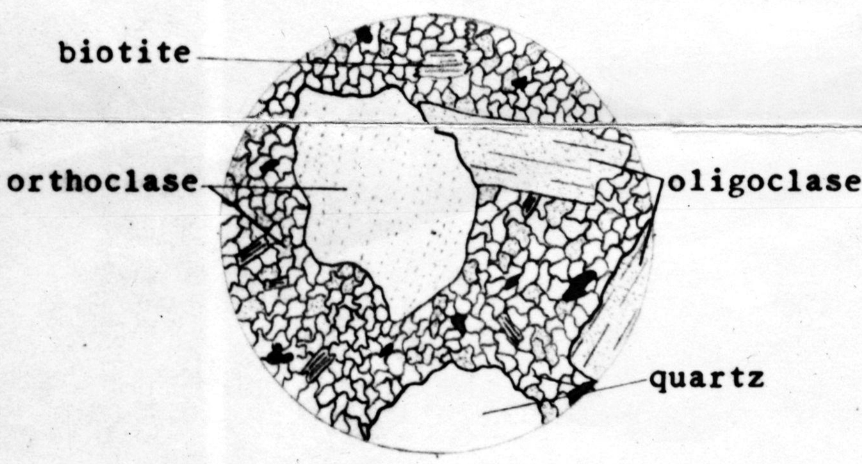
Figure 6.

Diam. 2mm. Phenocrysts of quartz, sodic plagioclase, and orthoclase. Groundmass shows incipient intergrowths of quartz & feldspar. Accessory biotite & magnetite.

BASALT

Figure 7.

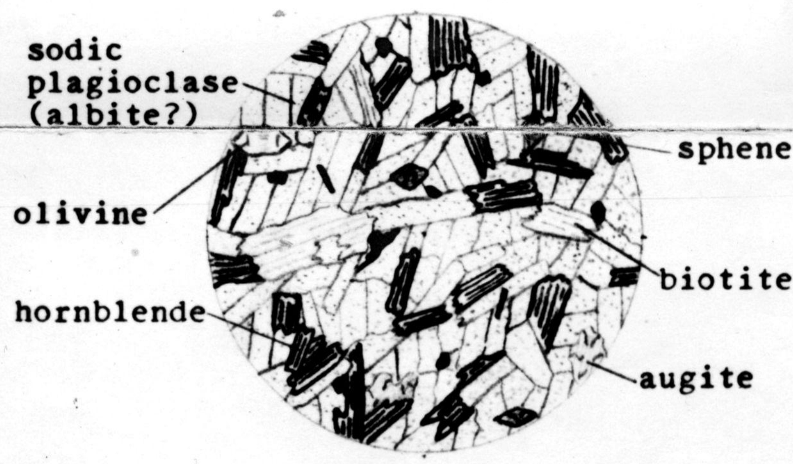
Diam. 2mm. Phenocrysts are labradorite, augite, and little olivine. Groundmass of interstitial labradorite laths with granular augite and glass.



QUARTZ LATITE

Figure 8.

Diam. 2mm. Holocrystalline texture. Phenocrysts of quartz, oligoclase, and orthoclase. Groundmass mosaic of quartz, feldspar, biotite, & magnetite.



LAMPROPHYRE

Figure 9.

Diam. 2mm. Sodic plagioclase, (albite?), about 50% of rock. Much hornblende and some biotite & augite. Iron ore, sphene, apatite, & olivine are accessory.

FIGURES 4--9.

Microdiagrams. COMMON IGNEOUS ROCKS OF THE NORTHERN MINERAL RANGE, UTAH